INCENTIVES FOR THE ADOPTION OF SOCIALLY BENEFICIAL TECHNOLOGIES: THE CASE OF AN E. COLI VACCINE

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ABSTRACT

Using the E. coli vaccine as a case study, this thesis examines the factors affecting the adoption of technologies with positive spillover (externality) effects related to food safety. Positive spillovers occur when the benefits from a technological innovation extend beyond the firm (farm) adopting the technology or they do not flow to the adopter. If there are insufficient incentives for the firm to adopt the new technology, adoption levels are sub-optimal, resulting in forgone benefits to society. These benefits include the avoidance of potential health costs, productivity loss and premature death costs as a result to exposure to E. coli *O157:H7*. Therefore, if the market incentives to adopt the technology are strengthened, adoption levels of the technology could reach socially optimal levels resulting in an improvement in food safety.

This has been the case in the Canadian cattle industry, where the uptake of the E. coli vaccine by cow-calf producers has been very low. As such, a number of potential incentives to increase adoption of the vaccine were identified and assessed through a survey of cow-calf producers on the Prairies. Data from the survey were analyzed using a stated preference methodology, Best-Worst Scaling, and Latent Class cluster analysis. A Binary Probit Model was also used to examine the factors affecting willingness to adopt the vaccine.

The results suggest that a significant number of producers were not aware of the existence of the E. coli vaccine. In addition, producers were most likely to be influenced in their adoption decisions by market/supply chain oriented incentives and government intervention incentives in the form of subsidies. On the other hand, incentives that were least likely to influence cow-calf producers' decisions to adopt included government intervention through recommending use of vaccine and neighbours (other cow-calf producers) adopting the vaccine. The Latent Class cluster analysis revealed the existence of three unique producer clusters with different attitudes

towards these incentives. Several socio-demographic variables and individual characteristics utilized in the Probit analysis were found to be determinants of a producer's willingness to adopt an E. coli vaccine. The implications of this research are such that producer education and awareness campaigns may be utilized as tools for disseminating information on food safety technologies such as the E. coli vaccine. Furthermore, the market/supply chain incentives may be used to form potential market-based solutions to address the current low adoption rates. The existence of three unique producer clusters suggest that a one-size fits all strategy to encourage the adoption of the E. coli vaccine might be difficult to implement and thus a more targeted approach may be a feasible alternative.

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DEDICATION

I dedicate this thesis to all the people that have nurtured and laboured for my success in this life. Although some are not here with us today, their willful spirit and impact still live on through my endeavours and continued pursuit of perfection, even though I know it does not exist. To you all, I say a gracious thank you, may God continue to use you to inspire others like you did myself. You all know who you are.

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CHAPTER 1

1. INTRODUCTION AND BACKGROUND

1.1. Problem Statement

The beef industry, particularly in North America, has been experiencing major structural changes. Food consumption that is more centered on the premise of healthy lifestyles, product safety, convenience and an assortment of other attributes related to food quality is becoming the norm. In addition, the growing sophistication of consumers has also contributed to increased scrutiny of production practices which encourages changes in the organization and coordination of business transactions and relationships within the beef sector (Brocklebank et al. 2008). These changes have taken the form of more complex supply chains that must coordinate a variety of resources such as genetics, extensive grazing, precision feeding strategies, high tech processing, cold chain logistics and, a key aspect of this thesis, food safety protocols (Brocklebank et al. 2008).

A widely publicized threat to food safety within the beef industry that has also shaped the transition to more complex supply chains has been the emergence of a bacteria based pathogen: E. coli *O157:H7*. As recently as Fall 2012, the vulnerability of the beef sector in Canada was highlighted with problems of E. coli contamination at an Alberta-based processing plant (XL Foods) that resulted in the largest beef recall in Canadian history. Various food safety technologies and innovations are currently available in the market, including an E. coli vaccine (Econiche) for cattle, however, Canadian cattle producers have been slow to adopt this technology in large part due to the benefits of adoption flowing elsewhere within the supply chain, mainly to processors/packers, retailers and consumers. The E. coli vaccine was designed with the intention of reducing the likelihood of cattle carrying the E. coli pathogen in their rumens, and also subsequently reducing the spread of this pathogen during the shedding process (excrement of fecal matter). This pathogen is a naturally occurring bacterium within the rumen and as such does not pose any harm or reduce the productivity of the cattle. The sole benefit of the E. coli vaccine therefore is to reduce the potential for E. coli contamination of meat products.

Using the E. coli vaccine as a case study, this project examines the factors affecting the adoption of technologies with positive spillover (externality) effects related to food safety. Positive spillovers occur when the benefits from a technological innovation extend beyond the firm (farm) adopting the technology. If there are insufficient incentives for the firm to adopt the new technology, adoption levels are sub-optimal, resulting in forgone benefits for society. If the market incentives to adopt the technology were strengthened, adoption levels of the technology could reach socially optimal levels resulting in an improvement in food safety.

1.2. Study Objectives

There are four main objectives to this research:

I. Examine the underlying economics of incentives to adopt socially beneficial technologies

II. Explore the barriers that currently exist towards the adoption of the E. coli vaccine by cattle producers

III. Examine whether incentives for adoption could be strengthened through closer supply chain coordination

IV. Discuss the implications for policies to enhance adoption of socially beneficial technologies.

This chapter is structured as follows. First, background on the development of pre-harvest interventions and E. coli incidences in Canada are discussed. Second, known foodborne illnesses resulting from various pathogens including E. coli are assessed with specific emphasis on their social and economic costs. Then, a detailed background on a brand of an E. coli vaccine - Econiche is discussed. Finally, an outline of the structure of the remainder of the thesis is provided.

1.3. Background

1.3.1. Emergence of Pre-harvest Interventions and E. coli Outbreaks in Canada

The E. coli *O157:H7* bacterium occurs naturally within the intestines of cattle and other similar mammals, while the animals themselves are not affected (asymptomatic carriers). E. coli contamination of food can occur in two major ways: first, through contamination of water irrigation supplies or ground water systems with manure run-off (which has been known to cause E. coli outbreaks in fresh salad and vegetable products as well as drinking water, as occurred in Walkerton, Ontario in 2000). These can be categorized as environmental sources of the E. coli pathogen. Second, E. coli contamination can also occur through cross-contamination from cattle hides to meat products or even raw milk as a result of shedding within a slaughter/dairy plant.

In a recent consulting report to the Canadian Food Inspection Agency (CFIA), Regulatory Impacts, Alternatives and Strategies Incorporated noted that policy makers' attempts to address the issue of E. coli incidences within the beef sector have thus far been concentrated at the processing level (RIAS, 2012). The authors went on to state that this has been achieved through the introduction of a variety of measures that have been designed to prevent E. coli from coming into contact with meat and by sterilizing carcasses during the processing stages. The CFIA's mandate in food safety regulations includes verifying that federally inspected beef slaughter and processing plants are effectively managing E. coli *O157:H7* risks at all the stages of production via an established required food safety control plan. Hazard Analysis Critical Control Points (HACCP)[1] (CFIA, 2013). CFIA inspectors are utilized in the field to make sure that the federally registered meat facilities are executing their identified critical control points in their everyday operations.

[1] Hazard Analysis Critical Control Point (HACCP) is an approach to food safety that is systematic and preventive. It goes beyond inspecting finished food products. It helps to find, correct, and prevent hazards throughout the production process. HACCP involves the identification of physical, chemical, and biological hazards, the identification of critical control points for mitigating these hazards, and the documentation of the management of critical control points (CFIA, 2012).

Policies such as requiring HACCP have assisted in the reduction of the prevalence of E. coli pathogen contamination within the Canadian beef industry. In Canada, mandatory adoption of HACCP occurred in 2005. Moreover, federally-registered fish establishments are required to follow a HACCP plan under the Quality Management Program (QMP) (CFIA, 2012). Although effective by most standards, and quite costly to processors/packers to implement, the incidence of E. coli outbreaks is still very much a reality, a costly one at that from both social and economic standpoints. The XL Foods E. coli case (August 2012) is considered to be the largest beef recall in Canadian history, where despite the preventative measures stipulated, an E. coli outbreak occurred with 18 persons reported to have fallen ill from exposure to contaminated meat products. D'Aliesio (2013) quotes the statistics on the final size of the recall at a market value of CAD $40 million. An independent report on XL Foods Inc by Lewis et al. (2013) reached the conclusion that a "weak food safety culture" and "relaxed attitude" to safety protocol was behind the breach.

Other E. coli outbreaks that have occurred in Canada include one as recently as October 2013, when an E. coli cheese related outbreak originating in British Columbia spread to Alberta, Quebec, Saskatchewan and Manitoba, prompting a recall. One person was reported dead and 20 seriously ill due to the ingestion of cheese made from raw unpasteurized milk (Canadian Broadcasting Corporation News (CBC News), 2013). In September 2004 an outbreak of E. coli associated with the consumption of beef donair occurred in Calgary, Alberta. Currie et al. (2007) noted that the beef donair concept originates from the Middle East and is a mix of ground beef and spices (sourced locally) molded into a cone that has become popular in parts of Canada. The authors went on to report that the Calgary Health Region received 12 reports of lab-confirmed E. coli infections with all these cases indicating that the victims ate at one of two locations of a local chain restaurant.

In addition to the cases mentioned above, Canada's worst ever E. coli contamination was environmental in nature occurring in Walkerton, Ontario in May 2000 as a result of run-off from a livestock farm into a nearby well, thus breaching the ground water supply. According to the CBC News (2010) 2,300 people fell ill while 7 were reported dead after drinking contaminated water from their taps at home. The E. coli vaccine is relevant in this case from the perspective that a reduction in the shedding of cattle has the potential to reduce the risk of environmental contamination, thus reducing contamination of ground water systems, and by extension municipal water supplies and horticultural farming operations dependent on underground irrigation systems.

While these remain isolated incidences, and the Canadian beef supply is generally considered very safe, the highlighted diverse incidences of E. coli contamination above serve as an indicator to industry stakeholders and also policy makers that more can be done beyond the slaughter and processing stages to prevent E. coli outbreaks. Furthermore, these incidents impose costs on the beef sector as well as on society. RIAS Inc. (2012) argue that, to date, policy makers have not specifically prioritized preventative pre-harvest interventions mainly because technologies such as the E. coli vaccine (Econiche) did not exist or were not commercially proven to be effective in arresting the E. coli pathogen. Pre-harvest interventions thus may have a greater role to play in reducing these incidences of E. coli contamination in tandem with the currently ongoing efforts in place at the various stages of the beef production process. As will be seen in the reviewed literature in section 2.2 of Chapter 2, pre-harvest interventions such as the E. coli vaccine have been proven to be efficacious in significantly reducing pathogens at the source, suggesting that they offer the potential to enhance the safety of the food supply system over and above existing post-harvest intervention methods.

A number of potential interventions have been introduced in both the post-harvest and pre-harvest stages of beef production as a means of addressing the E. coli pathogen. These interventions range from the use of vaccines, microbial probiotics designed to exclude or reduce microbial pathogens within the digestive tract of livestock, to bio-security measures which involve systems that monitor, certify and quarantine herds or flocks to ensure the occurrence of potential diseases is substantially minimized. Other intervention technologies available to assist in reducing the risks of E. coli contamination at processing plants include: electron-beam processing; irradiation; ethylene gas processing and steam pasteurization. Electron-beam processing utilizes high-energy electrons to kill germs; irradiation involves exposing food to a radioactive material, known as cobalt 60 to kill E. coli in the food, while ethylene gas processing involves food being placed in a room filled with the gas to kill any E. coli pathogens before being placed in another room to remove any leftover gas attached to the food (Teisl et al. 2001).

1.3.2. Foodborne Illness from Pathogens and its Social and Economic Costs

Crutchfield et al. (2000) maintain that North Americans enjoy access to an abundant, diverse and a relatively inexpensive food supply made possible by the domestic agricultural sector and imports of various food items from abroad. Nevertheless, the authors go on to suggest that despite the high level of safety of North America's food supply in relation to many countries around the world, foodborne diseases caused by bacteria, parasites, viruses, and man-made chemicals remains a public health issue.

The foodborne diseases caused by microbial pathogens are of interest in this thesis, particularly that of E. coli *O157:H7*. Table 1.1 shows E. coli *O157:H7* cases in the United States in comparison to other common sources of foodborne illnesses. From the table it can be ascertained that the E. coli pathogen lies right in the middle of the pathogen spectrum with reported cases totaling 62,500 in 1998, with fewer hospitalizations and deaths in comparison to Campylobacter, Salmonella and Listeria. It should be noted that comparable data for Canada proved to be difficult to find, however, information specifically on human E. coli incidences categorized by province was available, as can be seen in Table 1.2. Furthermore, more recent complete data were unavailable.

Table 1.1: Estimated Annual Extent of U.S. Foodborne Illness for Five Major Pathogens, 1998

Pathogen	Cases	Hospitalizations	Deaths	Costs US($Billion)
Campylobacter spp.	1,963,141	10,539	99	2.4
Salmonella, non-typhoidal	1,341,873	15,609	553	2.2
E. coli O157:H7	62,458	1,843	42	0.7
E. coli, non-O157:H7 STEC	31,229	921	26	0.4
Listeria monocytogenes	2,493	2,299	499	2.6
Total	3,513,694	3,513,694	1,604	8.3

Source: Mead et al. 1999

Table 1.2: Incidence of Human VTEC[2] cases in Canada per 100,000 population, 1995-2000

Province/Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
British Columbia	4.98	3.51	3.34	4.62	7.15	4.06	3.33	3.4	2.96	4.6
Alberta	3.99	4.29	4.88	7.97	6.5	10.85	9.42	8.41	5.92	8.96
Saskatchewan	5.03	3.04	3.54	3.73	2.96	4.27	6.2	4.42	n.a.	n.a.
Manitoba	14.08	9.17	6.78	7.56	6.74	7.58	5.21	6.4	7.06	4.87
Ontario	5.42	4.24	3.79	3.55	3.24	14.65	3	3.23	3.69	2.49
Quebec	4.72	4.15	5.09	5.18	6.17	7.35	4.54	3.51	1.78	2.04
New Brunswick	0.53	2.53	3.06	6.8	5.46	4.53	4.93	1.07	2.4	1.86
PEI	5.95	7.37	5.88	8.1	10.27	6.59	12.44	20.45	6.56	4.35
Nova Scotia	1.94	3.97	0.64	7.94	3.86	5.03	3.11	2.46	1.82	1.28
Newfoundland	2.11	0.36	0.18	1.3	1.31	0.57	0.96	1.73	0.77	0.39
Canada	**5.05**	**4.14**	**4.08**	**4.84**	**4.96**	**9.81**	**4.3**	**3.96**	**3.35**	**3.36**

Source: Grier and Schmidt (2009)

Following from the cases presented in Table 1.1, specifically E. coli *O157:H7*, hospitalizations and in extreme cases death lead to social costs such as productivity loss. These costs estimated in 1998 $Billions suggest that Listeria accounted for the majority of the costs to society, followed by Campylobacter, Salmonella and then E. coli *O157:H7*. According to Sockett et al. (2014) in Table 1.3 citing Canadian data, the medical cost of a case of illness caused by *E. coli* can range from $9 per case to over $500,000 in the most severe cases that result in End-stage Renal Disease (ESRD). Premature death as a result of pathogen exposure carries a value of statistical life worth $ 7.1 million (2012 dollars). Additionally, it was noted that the average number of work days lost can range from 0.25 for mild cases to 30 for severe cases with complications.

[2] Verocytotoxigenic

Table 1.3: Medical, Productivity, and Premature Death Costs per Primary Illness caused by VTEC Infection

Outcome	Medical Cost	Productivity Loss
Mild Cases	$9.56	$44.50 Avg. missing days: 0.25
Moderate Cases	$128.25	$536.40 Avg. missing days: 3
Severe Cases	$5,337.92	$1,251.60 Avg. missing days: 7
Hemolytic Uremic Syndrome	$24,661.04	$2,324.40 Avg. missing days: 13
End Stage Renal Disease	$534,652.42	$5,364.00 Avg. missing days: 30
Premature Death	Value of Statistical Life: $7.1 million (2012 dollars)	N/A

Source: Sockett et al. (2014) adjusted for 2012 wages and inflation. Estimated average hourly wage: $23.84 (Statistics Canada, September 2012a); estimated daily rate: $ 178.80 (calculated as $23.84/hour * 7.5 hours per day).

The most common symptoms of E. coli *O157:H7* according to Karch et al. (2005) are severe, acute hemorrhagic diarrhea and abdominal cramps on the milder side, where in most cases the illness subsides within five to ten days. In addition, the authors note that the more serious consequences of the bacterium can also cause hemolytic uremic syndrome (HUS) that can result in kidney failure (ESRD); lifelong dialysis; organ transplants, and neurologic sequela. E. coli *O157:H7* therefore has a potentially costly impact on human health.

The costs of an E. coli contamination also extend beyond the impacts on human health and include costs of product recall, damage to industry reputation and market access restrictions. For example, the Fall 2012 E. coli contamination at XL foods led to exporters of Canadian beef not only losing market access but also to suffer, in the short run, a damaged reputation. These effects were noted as far as Japan and Hong Kong, countries that imported beef products from XL Foods Inc. (Lewis et al. 2013). According to Trust for America's Health (2008) most food producers and food companies take safety issues very seriously and historically much of the innovation for improving food safety has come from within the food industry particularly at the post-slaughter level. However, the organization goes on to note that food producers, processors and retailers operate in markets and allocate their resources in response to market pressures and incentives, and thus far the pressure and incentives from the downstream players in the supply chain, mainly processors and consumers, do not appear to have been sufficient to push cattle producers to adopt the more effective pre-harvest innovations currently available in the market.

In relation to the use of vaccines as a potential intervention method to reduce the E. coli bacterium, a focus area of this research, there exists an E. coli vaccine (Econiche) marketed and distributed by Bioniche Life Sciences Inc. that has been approved by the Canadian Food Inspection Agency (CFIA) while holding provisional licenses in the United States and special certificate system in some countries in the European Union, particularly the United Kingdom. Econiche has been available in Canada since 2008 and has been the focus of quite a number of studies in relation to its efficacy and effectiveness. Smith et al. (2012), referencing a number of studies, suggests that the successful implementation of pre-harvest interventions, such as the E. coli vaccine in the cattle industry, require both efficacy and effectiveness to be demonstrated. Vogstad (2012) refers to efficacy as the ability of the intervention to decrease the likelihood of recovering Shigatoxigenic group of E. coli (STEC) *O157* from live cattle, while effectiveness refers to the actual usefulness of the intervention in the beef production system. The efficacy and effectiveness of a bovine E. coli vaccine product that utilizes three doses of type III secreted proteins was shown to reduce fecal populations of E. coli *O157:H7* in live cattle anywhere from 43% to 73% and 99% in relation to gut colonization according to Vogstad (2012). Section 1.3.3 provides more information on specific studies undertaken to ascertain the efficacy and effectiveness of the Econiche E. coli vaccine.

Despite the presence of a fairly robust E. coli vaccine marketed as a pre-harvest control, its availability to the beef sector and the demonstration of the vaccine's efficacy, the adoption rate of Econiche, currently estimated to be at 5%, has been minimal by any standard. Canadian cattle producers have been hesitant to adopt this technology in large part because the benefits from the adoption of the vaccine flow elsewhere within the supply chain, particularly to the processors/packers and the consumers of beef products. In addition to benefits flowing elsewhere, a potential adopter incurs costs of purchasing and administering the vaccine such as labour and veterinary costs.

Given the credence nature of this food safety intervention, other costs that can be incurred include third party verification costs and identity preservation costs arising from distinguishing one's product from the generic products in the market. The credence nature of food safety intervention creates information asymmetry within the supply chain as the vaccine adopter would have more information regarding his/her own intervention processes than the other stakeholders. The free-rider problem is also of concern if non-technology adopters benefit from the food safety enhancement created by adopters of the technology. These issues are discussed in more detail in Chapter 3, theoretical considerations. The development of the Econiche vaccine is discussed in more detail below.

1.3.3. The development of the Econiche vaccine

RIAS Inc. (2012) notes that the potential for an E. coli vaccine emerged several years ago when a laboratory at the University of British Columbia under the leadership of Dr. Brett Finlay made the discovery of how E. coli *O157:H7* secrete proteins and how these proteins have the potential to adhere to intestinal cells as a receptor. This discovery suggested the possibility that vaccination of cattle could reduce occurrences of human disease. Dr. Finlay subsequently approached the University of Saskatchewan, specifically the Vaccine and Infectious Disease Organization (VIDO), to assist in making secreted proteins to immunize cows. In-house experimental trials at the University of British Columbia showed evidence that vaccinating cattle proved to be an effective means in reducing E. coli shedding (RIAS, 2012).

The innovative new vaccine (Econiche) was subsequently licensed by Bioniche Life Sciences Inc., an Ontario based company which commissioned studies involving thousands of cattle to demonstrate the efficacy of the proposed vaccine. Guilbault (2011) reports that Econiche efficacy studies conducted under varying field conditions have been published in several peer-reviewed scientific publications (Potter at al. 2004; Van Donkersgoed et al. 2005, and Smith et al. 2009) where collectively the data supported the widespread vaccination of cattle using Econiche to reduce the shedding of E. coli *O157*. The author notes that it is important to take into account that the formulation of the product changed after the various trials prior to licensure.

Guilbault (2011) goes on to state that these changes proved successful in subsequent trials where, under conditions of natural exposure, vaccinated cattle were 98.3% less likely to be colonized by E. coli. This confirmed the efficacy of the vaccine to combat colonization as captured by

Peterson et al. (2007) and also the reduction of shedding and hide contamination as elucidated by Smith et al. (2009). In addition to these natural exposure conditions, subsequent efficacy demonstrations dealt with cattle artificially exposed to E. coli which only further proved vaccine efficacy and thus assisted with the commercial licensure of Econiche by the CFIA (Allen et al., 2011).

The E. coli *O157:H7* vaccine Econiche, the world's first cattle vaccine to reduce the E. coli *O157* pathogen threat, received full licensing approval in Canada in 2008. It should be noted that in addition to the commercial approval in Canada, Econiche also received provisional approval in the U.S. in the same year (which is still the case currently) and is on a special certificate system across various countries in the European Union; it received an import permit from the Australian Quarantine Inspection Service in 2011.

The vaccine cost has been reported to be approximately $3 per dose and has been authorized for use by the CFIA as a 3 dose regimen to be utilized at the pre-harvest (pre-slaughter level) by cattle producers at the cow-calf or feedlot stage (Grier and Schmidt, 2009). The authors note that, consistent with existing vaccination practices, beef/dairy calves would receive 2 doses of Econiche within the first 12 months of life, and animals over 1 year are recommended to receive 1 dose per year on an ongoing basis. The vaccine was intended to be available to cattle and dairy producers through their veterinarians, who would either administer it themselves or supervise the vaccination process. It should be noted that this thesis will only focus on the use of the E. coli vaccine in the beef sector while recognizing the fact that the vaccine is also applicable in the dairy industry, particularly on cull cows, an important source of beef.

Various sources of funding were used to finance the development and commercialization of the vaccine. Bioniche Life Sciences was granted a repayable loan in 2001 by Technology Partnerships Canada worth CAD $7.6 million for vaccine development and a CAD $5 million repayable contribution in 2007 from the federal government as support to scale-up vaccine production (RIAS Inc. 2012). Unfortunately, for a variety of reasons outlined in this thesis, the vaccine has not been broadly adopted by farmers, as the E. coli pathogen does not cause disease in cattle. The lack of financial incentives to incur this additional cost from the vaccine without any recoupment mechanisms in place has led to the market penetration of the vaccine to be estimated at 5% or less, according to Bioniche Life Sciences (Grier and Schmidt, 2009).

1.4. Outline

This thesis is organized as follows. First, Chapter 2 reviews, examines and assesses the literature surrounding the adoption of socially beneficial technologies with particular emphasis on the E. coli vaccine. The literature takes into account the efficacy and effectiveness of the vaccine; risk factors associated with E. coli; the barriers, incentives and cost and benefits of pre-harvest intervention and finally, consumer willingness to pay for foodborne pathogen intervention technologies. Following the literature review section, key theoretical considerations underpinning this thesis are discussed in Chapter 3 which shed light on the current trend of low adoption and serve as potential solutions: Market Failure; the Tragedy of the Anti-commons and Transaction Cost Economics. Chapter 4 outlines the methodology used for a Canadian cow-calf producer survey evaluating incentives to adopt the E. coli vaccine. Chapter 5 presents and analyzes the results of the cow-calf producer survey and discusses policy implications. The final chapter presents the conclusions, limitations of the research, and suggestions for further research.

CHAPTER 2

2. LITERATURE REVIEW

2.1. Introduction

This thesis deals with the under-adoption of a socially beneficial technology using the example of an E. coli cattle vaccine. Central to this thesis, therefore, is to assess the barriers that have hampered the adoption of the vaccine, as well as the incentives that could be instituted to increase adoption rates, and inform government and industry policy.

In order for adoption rates to reach socially optimal levels, an assessment of the barriers to adoption and the possible incentives is critical as these key components define the policy implications for the beef sector. This section presents economic literature relating to the barriers to adoption, the possible motivating factors that can change the current trend of non-adoption and the methodological techniques that have been used previously to model the adoption of socially beneficial technologies particularly the E. coli vaccine. The chapter is organized as follows: first the literature on simulation models and effectiveness of pre-harvest interventions is assessed, followed by the risk factors associated with E. coli. This is followed by the barriers, incentives and costs and benefits of pre-harvest interventions. Literature examining willingness to pay for foodborne pathogen technologies is explored, and finally an overall assessment of the reviewed literature is provided.

2.2. Simulation Models and Effectiveness of Pre-harvest Interventions

This section reviews literature on the efficacy of pre-harvest interventions, particularly the E. coli vaccine, in terms of its impact on the reduction of occurrences of pathogens through tackling the source. Jordan et al. (1999), using a stochastic simulation model, assessed the benefit of measures implemented in the pre-slaughter period to reduce the contamination of beef carcasses with shiga-like-toxin producing Escherichia coli *O157:H7*. The base scenario adopted was that of an abattoir processing approximately 1,000 head of lot-fed cattle per day. The control measures that were utilized by the researchers in the simulation included some that were hypothetical in nature so as to assist with the planning of research priorities. The measures included were based on either: the reduction in herd level prevalence of infection, reduction in opportunity for cross-contamination in the processing plant by re-ordering of the slaughter queue, reduction of concentration of E. coli *O157* in fresh faeces, or a reduction in the amount of faeces, mud and bedding transferred from the hide to the carcass. The authors noted that uncertainty over input assumptions was dealt with by allowing input parameters to be expressed as probability distributions.

The results of the simulations suggest that out of all the pre-slaughter measures, vaccinations paired with an agent that reduces the shedding of E. coli *O157* in faeces proved to have the greatest potential impact. Furthermore, it was noted that the rapid testing of all animals in the lot may be of some benefit in tackling E. coli, however knowledge of herd-test results obtained via testing a sample of animals can only provide a slight advantage in pre-harvest control programs. Another key finding from the simulation, according to Jordan et al. (1999), was that under most scenarios, there existed ample opportunities for cross-contamination to occur within the slaughter plant as a consequence of the early entry of cattle contaminated with E. coli *O157*.

Using the same stochastic simulation model, Signorini and Tarabla (2010) assessed the effects of measures implemented in the agri-food-chain in Argentina to reduce the contamination of ground beef with verocytotoxigenic (VTEC)[3]. The authors made use of an already existing published risk assessment model developed in Argentina as the baseline scenario for their study. Similar to Jordan et al. (1999), the authors employed control measures including a reduction in herd prevalence of infection as a result of vaccination, reduction in the opportunity for cross-contamination in slaughterhouses by the introduction of an on-line-hide wash cabinet, and finally the control of storage temperatures in slaughterhouses, in retail stores and in consumer households.

[3] VTEC is a particular group of the bacterium *Escherichia coli*. Although most strains of *E. coli* are harmless and live in the intestines of healthy humans and animals, VTEC strains produce a powerful toxin and can cause severe illness. The most common member of this group of bacteria is *E. coli O157:H7* (Crowley, 2011).

The simulations suggested that the greatest potential impact aimed at reducing VTEC prevalence and contamination in cattle hides in the initial stages of the agri-food-chain was associated with the hide wash cabinet and cattle vaccinations. The authors noted that the control of storage temperatures was deemed not to be effective, particularly if cross-contamination of carcasses with the pathogen was not prevented or curtailed. In addition to running the simulation with the above mentioned control measures, the authors also modelled the increase in feedlot production. The results showed that an increase in production (fattening) of cattle in feedlots has the potential to raise the risk exposure of VTEC infection and its sequelae. In a special point of departure, the authors postulated that although the pre-slaughter measures can prove to be effective in the control of VTEC, its greatest benefits can be realized when the post-slaughter controls are highly effective at reducing microbial growth. For example when the storage temperatures of ground beef in slaughterhouses, cutting and deboning, and retail and consumer households are under proper control.

Vogstad (2012), using the same simulation approach as the studies above, modelled the efficacy and effectiveness of Shigatoxigenic Escherichia coli (STEC) *O157* pre-harvest interventions on the premise that this pathogen is one of the leading causes of hemolytic uremic syndrome (HUS) in humans. The results of the research indicated that days from administration of the last vaccine dose did not significantly modify the measure of vaccine efficacy for a 3-dose regimen of a Type III secreted protein vaccine (TTSP) product. In relation to the usefulness of the vaccine, after 5000 simulations, vaccination with a TTSP vaccine was found to reduce summertime pen prevalence distributions of STEC *O157* to levels comparable to wintertime pen prevalence, with the major effect being the variability in fecal shedding prevalence.

Hurd and Malladi (2012), in developing a stochastic model, took a slightly different approach from the other simulation studies in that the authors evaluated the impact of E. coli *O157* vaccination as the only control measure on key epidemiological outcomes in the United States. The focus of the model was on the reduction in the prevalence of *O157* in feedlot cattle, as well as concentration in cattle faeces as a result of vaccination. The results of the simulation showed that vaccination can have a significant benefit with respect to certain relevant outcomes. These outcomes included: (i) the number of human *O157* illnesses due to consumption of ground beef, (ii) the number of production lots with high E. coli infection levels, (iii) the likelihood of detection by U.S. Department of Agriculture Food Safety and Inspection Service, and (iv) the probability of multiple illnesses due to ground beef servings from the same lot. Having established the literature on the efficacy and effectiveness of the E. coli cattle vaccine, the next section explores the risk factors associated with the pathogen.

2.3. Risk Factors Associated with E. coli

Synge et al. (2003) investigate the management factors that might play a role in influencing the shedding of verocytotoxigenic-producing Escherichia coli by beef cows in Scotland, where they noted unusually high rates of human E. coli infections. The authors sampled at least thirty-two herds on a monthly basis over approximately a one year time period for the collection of fresh pat samples and information on management factors. In similar style to the previous studies mentioned above, the faecal pat samples were tested for VTEC by established culture and immunomagnetic separation methods. Questionnaires were utilized during the monthly visits to farms to collect and record relevant management factors; this data was analyzed from both the univariate and multi-factor generalized least squares mixed model perspective.

The results of the study indicated that changes in the number of cows in a group, the presence of dogs and wild geese within the farm environment, housing arrangements and the feeding of draff (distillers' grains) proved to be statistically significant as risk factors in influencing the shedding of E. coli. The authors suggest that the event of calving appeared to reduce the likelihood of shedding, while any effects of weaning were not considered to be statistically significant.

Rugbjerg et al. (2003) performed a risk factor study on eight dairy herds found to excrete VTEC in Denmark previously used in a prevalence study. Similar to Synge et al. (2003) the authors attempted to tease out the associations between excretion of VTEC O157 and management factors. Factors such as housing and feeding were analyzed using a general least squares mixed model as in Synge et al. (2003); the authors stratified the animals in three age groups which were sampled four times during a one year time period.

The results of the study revealed that the risk of excreting VTEC *O157* was higher amongst weaned cows than non-weaned cows, which proved contrary to the results of Synge et al. (2003)

who found this particular variable not to be statistically significant. The researchers reported that calves aged 1-4 months showed a significant risk reduction if the calf had suckled colostrum from its mother or stayed for 2 days or greater with its mother after calving, similar to the significant result recorded by Synge et al. (2003). In addition, the authors noted that calves 5-24 months that had been moved within the last 2 weeks had a higher risk of exposure; however, this risk was averted if they were fed barley silage, unlike cows fed grain or molasses which recorded a higher risk of shedding VTEC *O157*.

A study by Nielsen et al. (2002) was designed with a two-fold objective in mind: to determine the prevalence of VTEC *O157* in Danish dairy herds and to investigate the relationship dynamics between the shedding of E. coli and a number of animal and herd characteristics. Sixty dairy farms were visited by the researchers once between the months of August – October, where faecal samples collected from each herd upward of 50 animals were analyzed for VTEC using similar methods to the studies above: enrichment, immunomagnetic separation, and plating on selective agar.

The results indicated that a strong effect of age was apparent with 2-6 month old calves as the high risk age group in contrast to calves < 2 months and cows. Moreover, a tendency of bull calves to have a higher prevalence than heifers within the age group of 2-6 months was found although not significant. It was also discovered and deemed significant that more of the herds characterised by having relatively many bull calves or many animals brought into the herd were positive for VTEC. The authors noted that no influence of herd size or housing conditions was found, which is contrary to some of the studies reported earlier.

Schouten et al. (2004) assessed the prevalence estimation and risk factors for E. coli on Dutch dairy farms. In order to estimate the prevalence of E. coli *O157* on Dutch dairy herds, the authors collected faecal samples from 658 randomly selected dairy farms from October 1996 – December 2000. Similar to Synge et al. (2003) and Rugbjerg et al. (2003), a questionnaire was administered on the farm characteristics enabling the researchers to generate variables that could be analyzed to identify and quantify factors associated with the presence of E. coli *O157*. The authors utilized a logistic regression with a sine function accounting for seasonality to analyze the variables obtained from the questionnaire to compare positive and negative herds. The results of the study suggested that the presence of at least one pig within the farm environment, the purchase of animals within the last 2 years before sampling, the supply of corn to the cows and a herd in the year 1999 or 2000 compared to sampling done in 1998 were linked to the incidence of E. coli *O157*.

In examining risk factors, Cernicchiaro et al. (2009) focused on identifying farm management factors associated with the prevalence of E. coli *O157:H7* among cattle in Ontario beef cow-calf operations. A total of 119 cow-calf operations in southern Ontario with at least 50 cows were visited between the months of June and December 2002. The researchers also employed the use of a questionnaire to collect information on characteristics such as farm size, cattle demographics, farm management practices, the presence of other livestock and wildlife and other aspects of the farm environment. A multivariable logistic model inclusive of random effects for farm and county was applied to determine the association between the prevalence of E. coli in cattle faeces and specified management factors.

The results of the study indicated that the presence of pigs within the farm environment was strongly associated with the incidence of E. coli in fecal pat samples, similar to Schouten et al. (2004). Furthermore, it was reported that the use of corn silage in winter was positively associated with the presence of E. coli in cattle faeces. Fairbrother and Nadeao (2006) in putting this into context, suggested that the contamination of silage can occur pre-harvest following a run-off of contaminated water or even the spreading of manure as fertilizer; in post-harvest via contamination from birds, rodents and other mammalian faeces during storage. Another risk factor encouraging the presence of E. coli that was identified to be significant by the researchers was that of taking cattle to shows. It was noted that this factor may reflect the opportunity for cattle to be exposed either directly or indirectly to the excrement of other animals.

Erdem and Rigby (2013) explore perceptions of a set of risks within a framework characterized by the level of control that rural (farmers) and urban respondents believe they have over the risks, and the level of worry the risks prompt. The risks considered by the authors include a set of food risks, both recently emergent (e.g., cloned animals) and longer established (e.g., hormones). In order to provide a broader context to their study, the authors follow the approach in Slovic (2010) and Sparks and Shepherd (1994) by including a number of non-food risks. The survey method features Best-Worst Scaling (BWS) which is explained in more detail in chapter four.

In relation to survey design and data collection, Erdem and Rigby (2013) note that twenty risks were included in the BWS survey, with half concerning food hazards and the rest non-food hazards. The experimental design comprised eight blocks (versions) of eight sets, with each set including five risks, where the number of risks included in each set was left to the determination of the researcher. Paper-pen surveys were conducted in the United Kingdom in the summer of 2009, where members of the general public in both urban (city of Manchester) and rural areas (agricultural shows) inclusive of farmers were sampled. Total observations amounted to 280 respondents, comprising 166 rural and 114 urban. The authors use best worst scaling (BWS) to elicit the levels of control respondents believe they have over risks and the level of concern those risks prompt.

The results of the study show that individuals have different perceptions of control and worry over the risks; gender has a significant effect on perceptions of control, but not on worry. Males are found, on average, to believe that they have more control over risks than their female counterparts. The authors state that among the food risks considered in the study, food pathogens are regarded to be the most worrying. They believe this is attributed to recent outbreaks and subsequent media coverage that play an important role in forming such perceptions. Salmonella and E. coli in particular, are regarded as more worrying than all other food risks such as bovine spongiform encephalopathy, food allergies, genetically modified ingredients, and pesticide residues, or hormones or additives in food. However, the authors note that people perceive E. coli slightly (6.8%) more worrying that salmonella.

The literature reviewed in the above sections examined the efficacy and effectiveness of the E. coli cattle vaccine, and the risk factors that may be responsible for the incidences of contamination. This information is useful in informing the design of the producer survey in terms of gauging cattle producers' knowledge of the E. coli vaccine and use of management factors that could contribute to E. coli contamination, such as housing arrangements and the presence of other animals within the farm environment. The following section examines the barriers, incentives, costs and benefits of pre-harvest interventions such as the E. coli vaccine.

2.4. Barriers, Incentives and Costs and Benefits of Pre-harvest Interventions

Based on the literature above, the E. coli vaccine was determined to be a fairly efficacious pre-harvest intervention capable of making a difference within the beef sector; the risk factors that can exacerbate the spread of the E. coli pathogen have also been well documented. However, despite this progress, the adoption of the E. coli vaccine as a pre-harvest intervention has not received much attention from the Canadian beef sector. This section presents literature examining the possible barriers that have made this the case, incentives/motivating factors that could be used to strengthen adoption incentives and previous cost and benefit analyses of the E. coli vaccine.

Ellis-Iversen et al. (2010) examined the perceptions, circumstances (intrinsic and extrinsic barriers) and motivators that influence the implementation of zoonotic control programs on cattle farms. The authors postulated that the implementation of disease control programs on farms requires an act of behavioural change. Such a postulate led to the use of a social-ecological model adapted from public health to investigate, communicate and explain a cattle farmer's decision-making process as it relates to zoonotic control. This model proposed four main stages of behaviour change: no intent, intent, implemented control and sustained control. Furthermore, it was noted that the model illustrates how intrinsic circumstances affect the intent to change behaviour as outlined by the Theory of planned behaviour (Azjen, 1985), and once this intent is obtained, how extrinsic factors influence the step from intent to action. This leads to this action having to be maintained to provide the desired outcome of a reduction in disease (Ellis-Iversen et al., 2010).

Field data from interviews conducted with 43 English and Welsh farmers were used in the study. An ordinal multivariable logistic regression was used to identify the motivators (private veterinarian, financial rewards or penalties, and consumer demand) associated with the different levels of implementation. The results of the study indicated that none of the interviewed cattle farmers had implemented programs to control zoonosis, with less than 50% having an intention of doing so. Moreover, the authors contended that the remaining farmers showed intent, but had not implemented any structured control program due to external barriers such as lack of knowledge.

The authors concluded that cattle farmers in general had positive attitudes towards controlling zoonosis on their farms and thus felt a responsibility to deliver safe products. It was noted however, that intent was often stalled by lack of belief in self-efficacy[4] and non-supportive social norms[5] while farmers without intent felt that advice through their private veterinarian would be the most effective motivator for program implementation. In addition, the results suggested that younger farmers and those with larger herds were more likely to place financial responsibility upon the industry rather than government.

Herath and Henson (2006) investigated the barriers that prevent the adoption of the HACCP food safety management system by food processing firms in Ontario, Canada. The objectives of this study were: to identify a set of barriers that prevent food processing firms from implementing HACCP; to quantify the seeming severity of these barriers; and to explore whether there are systematic categories of barriers that are comparatively more important than others. The study used a survey focused mainly on quality assurance managers/owners operators in food processing plants. Data was collected at the firm level with 134 food processing firms in Ontario receiving mailed questionnaires. The authors noted that the sample was stratified across three industries: (meat, dairy, and fruits and vegetables) and across 3 jurisdictional categories (federally registered, provincially licensed, and municipally inspected).

Through the review of the literature and an analysis of the survey data, the authors identified a number of potential barriers to the implementation of HACCP. The authors noted that respondents were asked to indicate the importance of each on a five-point scale from ‘very important’ (5) to ‘very unimportant’ (1). The results of the study across the entire sample revealed the most important barriers were associated with finance, namely internal budgetary constraints, and problems obtaining external funding. Questionable appropriateness of the management techniques; scale of changes required to existing production practices and the

[4] Defined by the author as the perception of the ability to carry out behaviour change in order to obtain a desired outcome

[5] Social norms derived from the perceived expectations of close contacts such as family, local community, faming/veterinary collaborators and industry partners.

overall scale of the changes being considered overwhelming were also found to be barriers to adoption of HACCP.

The food economics literature identifies three elements that increase incentives for firms/farms to adopt enhanced food safety controls: (a) product liability laws, (b) food safety law and regulation, and (c) market forces (see e.g. Buzby, Frezen & Rasco, 2001; Loader and Hobbs, 1999). Below these incentives and cost and benefit analyses are examined from a broader perspective.

Henson and Holt (2000) explored the incentives that motivate the adoption of food safety controls by businesses using a study of HACCP adoption in the UK dairy processing sector. Given that HACCP adoption in the UK dairy processing sector was made mandatory in May 1995, the authors wanted to investigate what other motivating factors outside of legal requirements fueled the adoption of this food safety control. In so doing, a mail survey was designed based on the existing literature on the implementation of HACCP and other quality management systems. A total of 1,196 firms were surveyed, with 240 questionnaires were returned and 192 of those being usable.

Using a factor analysis, Henson and Holt (2000) suggest that the decision by food manufacturers to adopt food safety controls is complex and is motivated by a number of public and private incentives either internal or external to the firm. The study put forward that market-based incentives relating to wider effects of food safety controls and which can influence business performance are also important motives for the adoption of HACCP. These included: improvements in efficacy/profitability, reduced product wastage, reduced customer complaints, retaining existing customers and/or attracting new customers, and enhanced product quality.

From these results Henson and Holt (2000) were able to distinguish the relative importance of individual incentives in the adoption of HACCP. The authors noted that these incentives clearly differed between firms, and subdivided firms into four categories according to their motivation for adopting HACCP: commercially driven; good practice driven; efficiency driven, and externally driven. External requirements were found to be a key factor in motivating the adoption of HACCP among larger firms that produced private-label products for food retail chains and for businesses manufacturing branded specialty products. Furthermore, the authors find that such businesses tended to adopt HACCP earlier than others and prior to the introduction of the legal requirement. On the other hand, efficiency was found to be an important motivating factor among businesses that produced generic products.

Henson (2008) explores the role of public and private regulation in motivating the adoption of enhanced food safety controls by firms in agri-food supply chains. The aim of his research is to provide an overview of the issues associated with public and private regulation and the related incentives to adopt enhanced food safety controls. The author notes that while the stringency of public regulation has been enhanced, and increased emphasis put on management-based food safety standards, private regulation is playing a greater role in driving the adoption decisions of firms. Furthermore, the author contends that firms face what he refers to as an inter-related series of incentives to implement enhanced food safety controls that reflect the blend of public and private regulations they face.

Henson (2008) suggests that it is increasingly becoming difficult to distinguish between public and private institutional forms of food safety governance. The author notes that these public and private standards are often inter-related, with the declaration of one dependent on how the other is evolving, while the traditional dichotomy between the "regulator" and "regulated" is breaking down. The author notes that the challenge for policy-makers is to understand the incentives associated with public and private regulation and to harness these in a manner that steers firms to make desirable food safety investments from a social welfare perspective.

In examining whether export orientation is a major incentive for the adoption of food safety systems among Turkish dried fig firms, Cobanoglu (2012) explores the hypothesis of whether this is a legitimate force behind export orientation. The author operates under the assumption that temporary and permanent employee numbers and the actual capacity of each firm could vary over a prolonged interval. Data was gathered from 91 dried fig businesses located in Aydin, Turkey via face to face interviews during May – August 2010.

The study uses a binomial logit model due to its simplicity and computational ease and estimates the model parameters using maximum-likelihood (Cobanoglu, 2012). The results of the study support the hypothesis considering that most dried figs produced in Turkey are exported to EU countries. Furthermore, these groups of countries (the EU) are also known to adhere to strict food safety regulations coupled with low aflatoxin limits. The majority of the firms thus appeared willing to implement these food safety practices fully. The author concludes that this dynamism compels the fig firms to adopt the appropriate and desired food safety compliances and practices. The parameters that were identified as influencing the decision to adopt included: contractual agreements with other firms; implementation of good practices by the dried fig farmers; export orientation and cost-benefit ratio (Cobanoglu, 2012). The estimated marginal effect suggested that when dried fig farmers are export oriented the probability that these firms will adopt food safety systems increases by 39.5%.

Cobanoglu (2012) introduced the idea of export orientation as an incentive for adoption of food safety controls. The Canadian beef sector exports their beef products as far afield as Japan, Hong Kong and 18 other countries according to Lewis et al. (2013). According to Statistics Canada (2006), more than one million head of live cattle were exported to the U.S. prior to the BSE outbreak. When this market closed the industry did not have the capacity to process these numbers and by the end of 2004 financial losses to cattle producers were estimated at $5.3 billion. South Korea, in similar stance to the U.S., placed a ban on Canadian beef following the BSE outbreak that lasted 8 years ending in January 2012, with industry estimates indicating Canadian beef exports to South Korea could total $30 million by 2015 (CBC News, 2012). These major export markets and other potential new ones make the author's assertions about export orientation very relevant to this thesis. This can translate to more secure export markets for Canadian producers who are willing to meet food safety driven market trends.

A quantitative assessment of economic incentives for firms in the red meat and poultry sectors in Canada to adopt food safety controls and the potential impact of a number of firm and market-specific characteristics on such behaviour is provided by Jayasinghe-Mudalige and Henson (2006). Data for this study was elicited through a postal survey with a national sample of red meat and processing plants in August to December 2003. The questionnaire included seventy-two statements derived from in-depth interviews, including five indicators for each of the ten incentive constructs and twelve statements. A total of 279 questionnaires were returned, representing a response rate of 34.2%.

The data were analyzed using the N-Vivo qualitative data analysis software which identified ten hypothetical distinct incentives based on the interview scripts. These included: (1) financial implications/cost; (2) impact on human resource efficiency; (3) impact on procedural efficiency; (4) "good practice"; (5) impact on sales, (6) impact on firm reputation; (7) commercial pressure; (8) existing government regulation; (9) anticipated government regulation, and (10) product liability laws. The overall results suggest that the anticipated impact on sales and the reputation of firms are the predominant drivers behind the food safety responsiveness of plants in the Canadian red meat and poultry processing sector. These results may indicate that firms are likely to be most responsive to the need to upgrade their food safety controls in the presence of potential gains in relation to increased market revenue. Moreover, "good practice" was also found to be a strong motivating factor, suggesting that numerous firms implement food safety controls simply because they perceive it to be the right thing to do.

In a theoretical study of traceability and liability incentives, Pouliot and Sumner (2008) explore in detail the relationship between traceability and the provision of food safety, where traceability facilitates the assignment of liability to individual firms for possible lapses in food safety. In other words, traceability was proposed as a motivating factor in the adoption of food safety controls given the potential it may create for identifying the source of the lapse. The authors set out to show how traceability can increase the supply of safe food via allocating liability using a two-stage marketing channel formal model with homogeneous farms that sell raw material to homogeneous marketers who sell food to consumers. They argued that it is easy for firms to remain anonymous in the absence of traceability exposing the supply of safe food to the free-rider problem. With the lack of proper traceability mechanisms, the authors noted that liability incentives are severely dampened for upstream firms/farms due to the imperfect nature of information being transmitted through the marketing chain.

Moreover, Pouliot and Sumner (2008) argue that the lack of traceability per se should be viewed as a problem not only for consumers but also for food firms within the supply chain as, without traceability, upstream firms are unable to transfer liability to their suppliers once a problem occurs at earlier stages. The inverse also holds in that the increased traceability in the early stages of production can shift liability to upstream firms. Liability costs and potential loss of reputation associated with publicized lawsuits can also create significant incentives for firms and farms in the supply of safer food leading to the reduction in societal costs of foodborne illnesses (Pouliot and Sumner, 2008). The results suggest that downstream firms show greater potential using traceability back to the farms in order to shift liability upstream and reduce the chance of food safety occurrences.

Cost and benefit analyses have been carried out concerning the E. coli vaccine Econiche. These types of assessments quantify the private and public costs and benefits arising from non-adoption or adoption of the vaccine. Grier and Schmidt (2009), providing an updated version of the 2007 George Morris Report submitted to Bioniche Life Sciences, endeavoured to determine the economic benefits of an E. coli *O157* control program involving the immunization of Canadian cattle. The authors argued that the E. coli pathogen has several negative impacts: sickness, death, industry costs and lost demand for specific food products. The authors argue that Econiche can reduce E. coli *O157* in cattle herds, the reduction or elimination of these problems can be viewed as the potential benefits of Econiche. A cost/benefit analysis was used by the researchers to ascertain whether the benefits flowing from Econiche outweigh the costs accruing to the industry due to an Econiche vaccination program.

In their analysis, the authors assumed a 100% utilization rate for the vaccination program for two major reasons: given the ultimate goal was to have the entire herd vaccinated, full costs of such an activity needed to be thoroughly taken into account. Secondly, it was noted that the tabulated benefits were done under the assumption that E. coli has been mostly reduced from the available herd in Canada which is only possible if the majority of the animals are vaccinated. According to Grier and Schmidt (2009) the cost/benefit analysis yielded an approximate cost/benefit ratio of 3:1. A summary of the benefits of the Econiche vaccination program totalled $103 million per year from the reduction or elimination of medical costs - $21 million; recalls and industry costs - $4 million, and loss in demand - $78 million. On the other hand, the cost of the Econiche vaccination program to the industry was estimated to be $35 million annually, which primarily depends on the number of doses to be administered and on herd numbers. From this it was determined that the benefits of the product would exceed the annual estimated costs by $68 million per year leading to the estimated cost/benefit ratio of 3:1.

The literature reviewed in this section makes it clear that barriers to adoption exist with most food safety technologies, and to mitigate against such barriers, various regulatory or market incentives that can reverse the low adoption may be necessary. Cost benefit analyses are useful in this context in painting the pros and cons of the technology and the intended method of application. Such analyses have the potential to influence interested parties' willingness to pay for foodborne pathogen intervention technologies, which is discussed in the next section.

2.5. Willingness to Pay for Foodborne Pathogen Intervention Technologies

Willingness to pay (WTP) studies, although in most cases hypothetical, allow for one to examine the socio-economic factors that drive the decisions of respondents toward a particular action. The review of such literature has the potential to inform the direction of this thesis. A survey of Canadian cattle producers authorized by Bioniche Life Sciences and executed by Strategic Research Associates (2010) was created with the objective of understanding producer willingness to implement animal treatment on the farm to reduce public health risks. Furthermore, the study aimed to understand how strongly producers felt about participating in a national vaccination program under different scenarios. The researchers conducted 771 telephone interviews among a random sample of Canadian beef and dairy farmers. The survey was divided into four major categories: awareness, information, willingness and attitudes towards paying. The results of the survey, statistically significant within +/- 3.5 % revealed that 75% of the producers were familiar with E. coli. In addition, the majority of producers expressed price sensitivity regarding the cost of the vaccine. The research firm also reported that 87% of producers felt it was important to take action to prevent on-farm contamination of food products with E. coli.

A large literature has emerged on consumers' willingness to pay for food safety or food safety assurances. Most of these studies have evaluated WTP for food with stronger levels of food safety, but in an interesting departure, Mukhopadhaya et al. (2004) estimate consumers' willingness to pay for a hypothetical vaccine that would protect a consumer against major foodborne pathogens. Using contingent valuation (CV), the authors estimate WTP for protection over a variety of durations ranging from (1 year, 5 years, 10 years and lifetime protection) against Salmonella, E. coli or Listeria. A further objective of the study was to assess the factors that impact the WTP responses elicited. The data for the study was obtained from the U.S. Foodborne Diseases Active Surveillance Network (FoodNet) through randomly selected telephone interviews spanning 9 states over a 12 month period in 2002 yielding 5,293 observations. A combination of logit and Tobit models were used in the estimation of the economic benefits of food safety against the aforementioned foodborne pathogens.

The results of the study indicated that consumers were not only willing to pay for protection against foodborne pathogens but pay more for a protracted protection. Moreover, the respondents stated that they would pay more for safeguard against E. coli exposure in relation to Salmonella or Listeria; conversely, consumers were less willing to pay if the protection proved to be costly. The factors affecting WTP included a respondent's education, household income and whether they live in a rural or urban setting.

Focusing on a food processing technology, Nayga et al. (2006) explored consumers' willingness to pay for irradiated ground beef with survey respondents having been provided with information about the nature of food irradiation and what it entails. Taking a different approach from previous studies, the authors estimated consumer WTP using a non-hypothetical experiment with actual products (irradiated ground beef), cash, and an actual exchange. Data were collected at selected stores of a regional supermarket chain in Austin, Houston, San Antonio and Waco, Texas from March to June 2002. The researchers further noted that instead of using an auction elicitation mechanism, a face-to-face WTP dichotomous choice field experiment provides a more familiar setting for consumers and thus yields more accurate estimates.

Using the data gathered from the dichotomous choice experiments, the authors estimate consumer WTP for irradiated foods utilizing the traditional single bounded approach and the one & one-half bounded approach based on similar works of Cooper et al. (2002). The results suggested that many individuals are willing to pay for foods that have undergone irradiation once they have been adequately informed about the nature of the technology and its capabilities in reducing the risk of foodborne illness. In addition, WTP estimates indicated that respondents were willing to pay a premium of $0.77 for a pound of irradiated ground beef, which proved higher than the actual cost to irradiate the beef product (Nayga et al. 2006).

According to Teisl and Roe (2010), governments often use cost-of-illness approaches to value reductions in morbidity. However, the authors note that this approach has been criticized by economists as it has the tendency to undervalue the benefits accrued from a food safety improvement initiative. With this context in mind, Teisl and Roe (2010) administered a national survey to 3,511 adults in the U.S. including a hypothetical food-choice experiment in order to provide more accurate and wide-ranging measures of consumer WTP for food safety improvements. The authors argued that their proposed approach was an improvement from previous evaluations of food safety improvements due to: (i) they provided the respondent with information regarding the promised change in the probability of pathogen exposure in retail food packages rather than changes in the probability of falling sick. (ii) They elicited changes in respondents' subjective probability of falling sick, and (iii) they elicited forecasted changes in the quantity demanded for products that have undergone food safety improvements.

In the choice experiments the described product was either exposed to Listeria or E. coli; the food type used in the surveys was either hotdogs or hamburgers, while the process used to eliminate the pathogens was either electron beam (irradiation) or ethylene gas processing. Given that the cost-of-illness approach fails to place value on key aspects of individual morbidity, such as pain, suffering, lost leisure time and worry, the inclusion of these aspects in the WTP estimate is a strength of this approach. The results yielded large estimates commensurate with the expectations compared to existing estimates for improvements in food safety. Furthermore, this result held true even when the authors adopted conservative assumptions at key stages of the estimation process.

In addressing a void in the literature, Marette et al. (2012a) investigated consumer willingness to pay for food safety human vaccines and simulated the impact on social welfare resulting from the subsidization of consumer vaccines from two possible industry reactions. These two industry reactions took the form of the status quo: maintenance of current food safety vigilance or reduced food safety vigilance as a result of a moral hazard[6], which in this case is the use of vaccines by consumers. The authors' use of stated preference data, obtained from the FoodNet survey from U.S. residents over a 12 month period allowed for the estimation of consumer response to vaccines that would protect the individual from Salmonella, E. coli or Listeria across various time periods of protection (1 year, 5 years, 10 years, or lifetime protection) in similar style to Mukhopadhaya et al. (2004). Unlike previous vaccine analyses, models of three distinct

[6] Moral hazard is defined in this context as the lapse of pathogen intervention standards by industry players due to the fact that consumers are protected from possible pathogens by the use of human pathogen vaccines.

aspects of a respondent’s decision-making process were captured using binary and Ordered Probit models: the choice of being vaccinated, the subjective estimate of the probability of contracting the illness, and finally the subjective assessment of the severity of illness.

The results as reported by Marette et al. (2012a) showed a large consumer WTP if vaccines are reasonably inexpensive, while the existence of anticipated moral hazard has an upward effect on consumer WTP and their voluntary uptake of a vaccine. In addition, the estimated vaccine price and probability of illness parameters confirmed *a priori* expectations of not only being significant but showing that respondents are much more likely to become vaccinated if they recognize that eating food will result in no illness after vaccination. Similar to Mukhopadhaya et al. (2004) the researchers reported that individuals were more likely to purchase the vaccine if it controlled for E. coli as compared to Listeria or Salmonella.

Building from the previous study, Marette et al. (2012b) explored the notion of the development of human vaccines as a means to combat the threat of foodborne pathogens by investigating how this introduction could alter consumer and producer behaviour in the food markets that are subject to these pathogens. The authors built a partial-equilibrium model of the US beef sector that addresses this behaviour from the perspective of foodborne illness damages formed by E. coli contamination. The model was calibrated using parameters from the previous econometric studies of the US beef sector and stated preference studies on the uptake for such innovations.

From the calibrated model, three scenarios were simulated: the introduction of a vaccine; the tightening of pathogen standards for beef production; and lastly the concurrent introduction of both vaccinations and tighter standards. The results of the simulation showed that all the proposed policies have the potential of increasing the aggregate surplus given most calibrated scenarios with the authors attributing the largest effects to the introduction of vaccines. Furthermore, such an intervention leaves a firm’s marginal beef production costs unchanged (or lower by taking moral hazard into consideration), which can stimulate beef demand amongst those protected. However, those consumers who decide not to get vaccinated whether they are aware of the vaccine or not, experienced no change in expected damages (or a higher expectation of damages taking moral hazard into effect) but nonetheless faced a higher price of food due to the more robust beef demand from vaccinated consumers (Marette et al. 2012b).

2.6. Assessment of Reviewed Literature

The literature reviewed above highlights the diversity of the works concerning socially beneficial technologies, with special emphasis placed on the E. coli vaccine cases. From the literature, it is evident that these types of innovations have been proven to be efficacious and fairly effective as pre-emptive measures and strategies in combating the growth and spread of pathogens. Moreover, the WTP studies reveal that consumers are willing to pay in order to benefit from the use of these technologies which perhaps highlights future market possibilities. The studies by Jordan et al. (1999) and Signorini and Tarabla (2009) confirm that vaccination as a mechanism of addressing pathogens such as E. coli is efficacious and effective, thus suggesting that there is a place for such innovations within the beef supply chain if the barriers and incentives can be adequately addressed.

In relation to some of these barriers, Ellis-Iversen (2010) asserts that a significant portion of farmers had showed intent towards the adoption of a possible zoonotic vaccination program. However, the implementation of any such structured control program was curtailed due to the existence of external barriers such as lack of knowledge. Other types of barriers may present themselves in the form of various costs that the industry might have to grapple with while attempting to determine the benefits of adoption of various socially beneficial technologies as expounded by Grier and Schmidt (2009) in their cost and benefit analysis. In addition to the barriers mentioned above, Herath and Henson (2005) in assessing the adoption of HACCP systems identified the most important barriers as associated with financial constraints, questionable appropriateness of management techniques and the scale of changes required to existing production practices.

To counter some of these barriers, the industry (private) or government (public) can provide relevant incentives to stimulate the adoption rates of innovations such as the E. coli vaccine so as to allow the public to benefit from increased food safety standards. Henson (2008) raised the notion that private standards are playing a greater role in driving the adoption decisions of firms/farms. Government intervention may not be necessary if the private sector is assertive enough to recognize the industry's needs and align itself accordingly in a manner that steers firms/farms to make desirable food safety investments from a social welfare perspective. This alignment can involve the adoption of relevant socially beneficial technologies under the right stimulus. Perhaps a way for the private sector to achieve this can be through the use of supply chain strategies such as branded beef programs where certain sought after attributes can be realized through supply agreements. A good example of a branded beef program would be that of A&W and its recent *better beef* (hormone free) *campaign*, which is sourced from carefully selected supply chain participants (McKenna, 2013). Pouliot and Sumner (2008) suggest the use of enhanced traceability coupled with liability as having the potential of creating stronger incentives for adoption.

The presence of incentives is however not a guarantee for adoption of these types of technologies. As highlighted by Ellis-Iversen et al. (2010), barriers such as lack of economic pressure from either the government or industry, particularly from processors/packers and consumers can inhibit adoption. The X-inefficiency concept can be used in this instance to capture the current under-investment by the beef supply chain participants. The X-inefficiency concept suggests that there exists a positive relationship between external pressures on a firm and effort exerted by employees (Leibenstein, 1966) cited in Church and Ware (2000). The absences of pressure from consumers to retailers, and in turn retailers to processors/packers, processors/packers to cattle producers may have contributed to the non-adoption of socially beneficial technologies such as the E. coli vaccine, in addition to the fundamental issues of spillover effects.

Marette et al. (2012a) and (2012b), in assessing human vaccines as a means of combating foodborne pathogens, highlight the issue of the moral hazard problem that may present itself in the event that consumers are inoculated to protect them from various pathogens. In other words moral hazard arises if other supply chain participants relax their efforts in terms of the preventative steps they take to reduce or eliminate E. coli because of the belief that since consumers are vaccinated the risk of foodborne illness is lowered.

Roe (2004) refers to the above phenomenon as a lulling effect and continues to note that this effect is pertinent to foodborne illness whereby there is potential for bilateral damage: one agent's effort affects the marginal effectiveness of the other agent's efforts. The author goes on to postulate that for most foodborne illnesses caused in the home setting, consumers have the ability to alter damages by simultaneously changing their preventative efforts according to the industry's preventative efforts.

Taking the above in this study's context, if cattle producers decide to adopt the E. coli vaccine as a pre-harvest intervention in the early stage, there is potential for a similar lulling effect occurring within the supply chain where the processor/packer eases their preventative efforts with the belief that the measures taken by the cattle producer are enough to compensate for the relaxation of standards and procedures in reducing the prevalence of E. coli in beef products. In other words, if cattle producers perceive that others in the supply chain might do this then this may be yet another disincentive for them to vaccinate. This perhaps highlights the fact that the reduction or elimination of such pathogens is going to take continuous effort at each stage of the supply chain by the various stakeholders. Roe (2004) states that under such technologies, socially optimal prevention often requires one party to exert considerable effort while the other party exerts little effort, which explains the current dynamics within the Canadian beef supply chain regarding such preventative technologies. This statement makes it even more relevant to examine the barriers, and particularly the incentives that can be put in place to bring equity for this considerable effort required by the one party.

In similar style to some of the studies that have been highlighted in the reviewed literature, this study endeavours to investigate and explore the barriers that are currently proving to be a deterrent for Canadian beef producers in widely adopting socially beneficial technologies with particular emphasis on the E. coli vaccine. These barriers will be made more apparent through the conceptual framework which follows. Furthermore, incentives to adopt food safety controls, the main focus of this study, will also feature heavily as part of the investigation. Following the examples of the literature, this thesis utilizes a producer survey to determine the potential effectiveness of various incentives to adopt an E. coli vaccine. It should be noted that in attempting to fill a gap in the literature, this research also intends to look at the possibility of closer forms of supply chain co-ordination as a potential of strengthening adoption.

CHAPTER 3

3. THEORETICAL CONSIDERATIONS

3.1. Introduction

Several theoretical frameworks can shed light on the low adoption rates of the E. coli vaccine and other technologies whose benefits spillover into different sectors or different stages of the supply chain, as well as potential solutions. These theoretical frameworks include: Market Failure; the Tragedy of the Anti-Commons, and Transaction Cost Economics (TCE).

3.2. Market Failure

The prospect of market failure, in this instance where private markets have failed to bring about the socially optimal allocation of resources, takes all of its three forms: public goods/externalities (positive) and information asymmetry.

3.2.1. Public Goods/ Externalities

As indicated in Chapter 1, the availability of the first ever E. coli vaccine to be sanctioned and approved in Canada and worldwide has proven not to have many takers within the Canadian beef industry. A key reason is due to the vaccine possessing attributes (food safety benefit) that might deem it a public good. Public goods are known to exhibit two major characteristics: that of non-rivalry and non-exclusivity. If a cattle producer decided to adopt the E. coli vaccine within the current supply chain structure, the producer will not be able to prevent other parties (free-riders) from benefiting from his/her positive spillover/externality of investment whilst still incurring the additional costs.

The food safety benefit as a result of an E. coli vaccine exhibits the characteristics of a public good in the sense that the adopter cannot prevent everyone within the beef sector from obtaining this benefit (non-exclusivity); every industry player can use this benefit at the same time without inhibiting the utility of another (non-rival). The benefit in this case is the reduced prevalence of

E. coli outbreaks in the beef industry that impact many beef producers (i.e. preventing the types of disruption to beef supply chains and market access that occurred in the XL Foods outbreak). The combination of the two characteristics results in a free-rider problem. The free-rider problem makes the market very inefficient in supplying public goods. A classic example is streetlights, where if one decides to invest in streetlights to improve one's own safety and the neighbour receives the same benefit at no cost, this becomes a free-rider problem because they cannot exclude others from consuming the street lights.

In the presence of public goods the Marginal Social Benefit (MSB) is greater than the Marginal Private Benefit (MPB). This reflects the current market situation in the Canadian beef sector where the MSB from vaccinating cattle from E. coli is greater than the MPB as there are unaccounted external benefits that accrue to other supply chain participants and to society at large as a result of vaccine adoption. Therefore, in order for cattle producers to adopt such a technology to socially optimal levels, MPB will have to be equal to or greater than the MSB. The resulting deadweight loss (DWL) forgone to society can be addressed through various incentives which will be one of the primary focus areas of this research.

Related to a public good is the concept of an externality. McConnell et al. (2010) describes an externality as a cost (negative externality) or benefit (positive externality) accruing to an individual or a group, a third party that is external to a market transaction. In this sense, a positive externality is a form of public good. Externalities are benefits or costs from production or consumption accruing without compensation to non-buyers and non-sellers of a product.

Figure 3.1 below shows the mechanics of a positive externality/spillover which leads to under-production or under-allocation of a resource because the market demand, D (MPB) does not take into account the full benefit of the resource being produced. McConnell et al. (2010) suggest that the market demand curve only reflects the direct private benefits to the producer but does not reflect the external benefits, the positive externalities that accumulate to every other party in D_t (MSB). The outcome of this is that the equilibrium output Q_e is less than the optimal output Q_o thus in this instance the market fails to produce enough E. coli vaccinated cattle leading to a lower demand for the E. coli vaccine which translates to under-allocation for this resource and therefore loss in market efficiency as captured by the DWL.

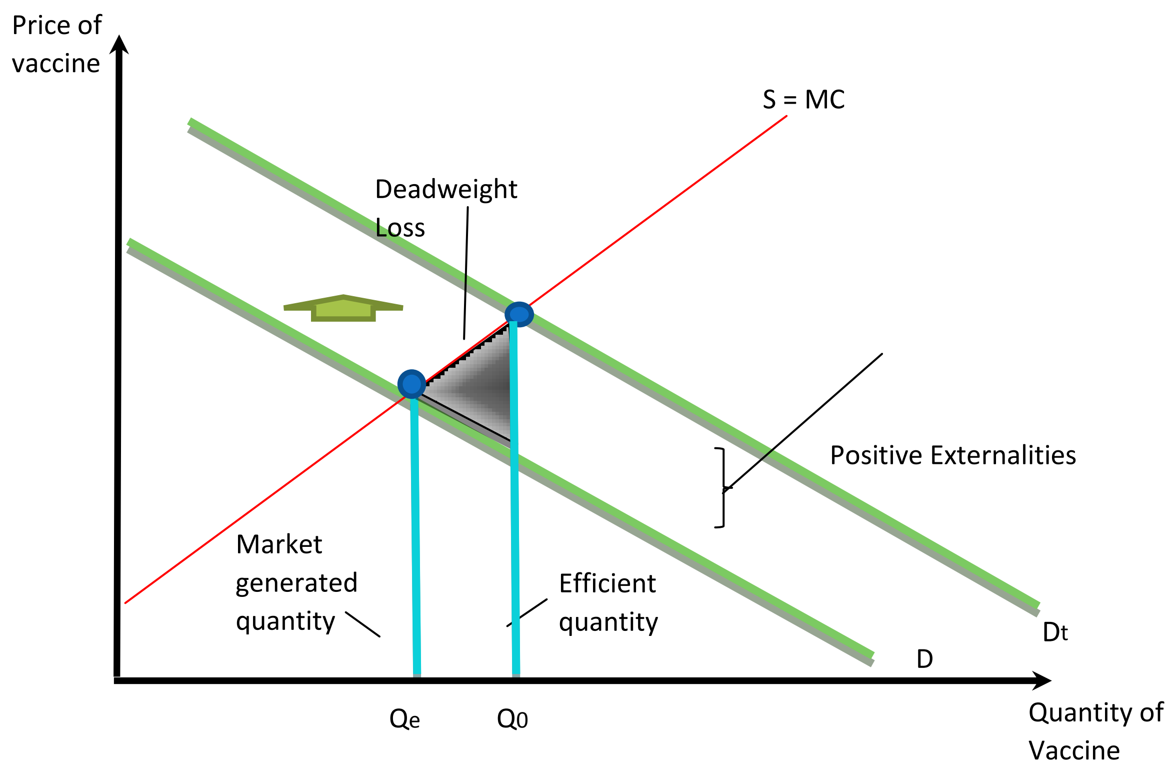

Figure 3.1: Graph depicting the effect of a Positive Externality in the Market for Vaccine
***Source*:** McConnell et al. (2010)

3.2.2. Information Asymmetry

Another source of market failure results when market players have insufficient or inaccurate information and their cost of obtaining better information is prohibitive. McConnell et al. (2010) state that asymmetric information is where unequal information is available to buyers or sellers about price, quality, or some other aspect/attribute of a good or service. Complete information is necessary in the market in order for goods and services to be exchanged in an efficient manner. In the absence of such, insufficient or inaccurate information makes it difficult for the market to differentiate between trustworthy and untrustworthy sellers or buyers or high or low quality creating the classic market for lemons problem.

In the case of the E. coli vaccine, it is quite difficult for market players to distinguish between cattle that have been vaccinated and ones that have not undergone this treatment. To illustrate, suppose we have E. coli vaccinated cattle and non-vaccinated cattle misrepresented as vaccinated cattle available in the beef market. When an E. coli outbreak creates a shock in the beef market, the market demand curve for the entire industry is affected; this is also inclusive of those cattle producers who invested in the vaccine technology. Consumers, and presumably also processors and retailers in such a scenario are unable to distinguish between the two products in the absence of quality verification and thus penalize both the trustworthy and the untrustworthy products by decreasing their consumption. This is akin to a pooling equilibrium where both high quality and low quality goods are pooled, resulting in a reduction in demand due to quality uncertainty.

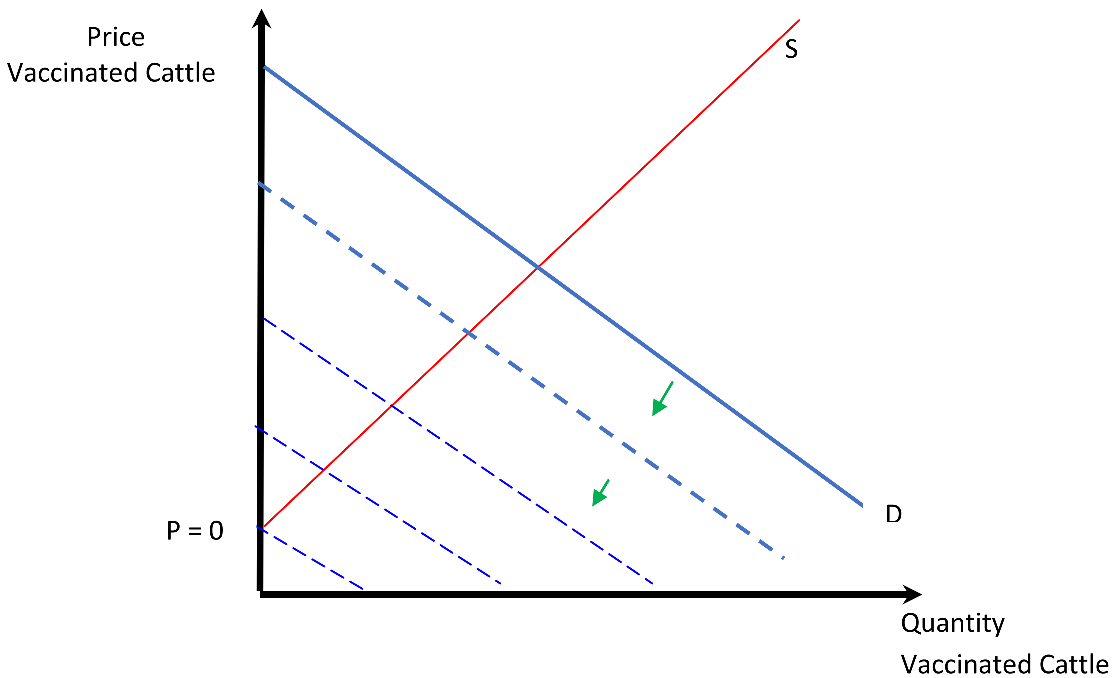

Figure 3. 2: Graph depicting the effect of Information Asymmetry in the Vaccinated Cattle Market

Figure 3.2 shows the demand for vaccinated cattle by potential buyers in the presence of information asymmetry. Given the difficulty in distinguishing between a lemon and a non-lemon as a result of the pooling effect mentioned above, the perceived quality uncertainty leads to the decrease in the demand of vaccinated cattle causing leftward shifts. As a result of the decrease in demand for vaccinated cattle, cattle producers operating in vaccinated cattle operations may be skeptical of this market leading also to the drop in demand of the vaccine technology. Overall, as long as there are potential E. coli shocks in the beef market and information asymmetry between buyers and sellers, the demand curve for vaccinated cattle will continue to shift leftward to the point where even a lower price of vaccinated cattle might not seem attractive to potential buyers (P = 0).

Figure 3.3 illustrates an alternative way of looking at the market failure problem as a result of information asymmetry. As a result of asymmetric information, the market under-provides vaccinated cattle due to quality uncertainty as consumers cannot tell the difference between a lemon and a quality product as captured by D^u. However, with the availability of full information, consumer demand could be higher as mechanisms would be in place to ascertain the authenticity of the vaccinated cattle as showed by the demand curve $D^{F.}$ In the absence of full information however, there is an inefficient allocation of resources leading to a deadweight loss.

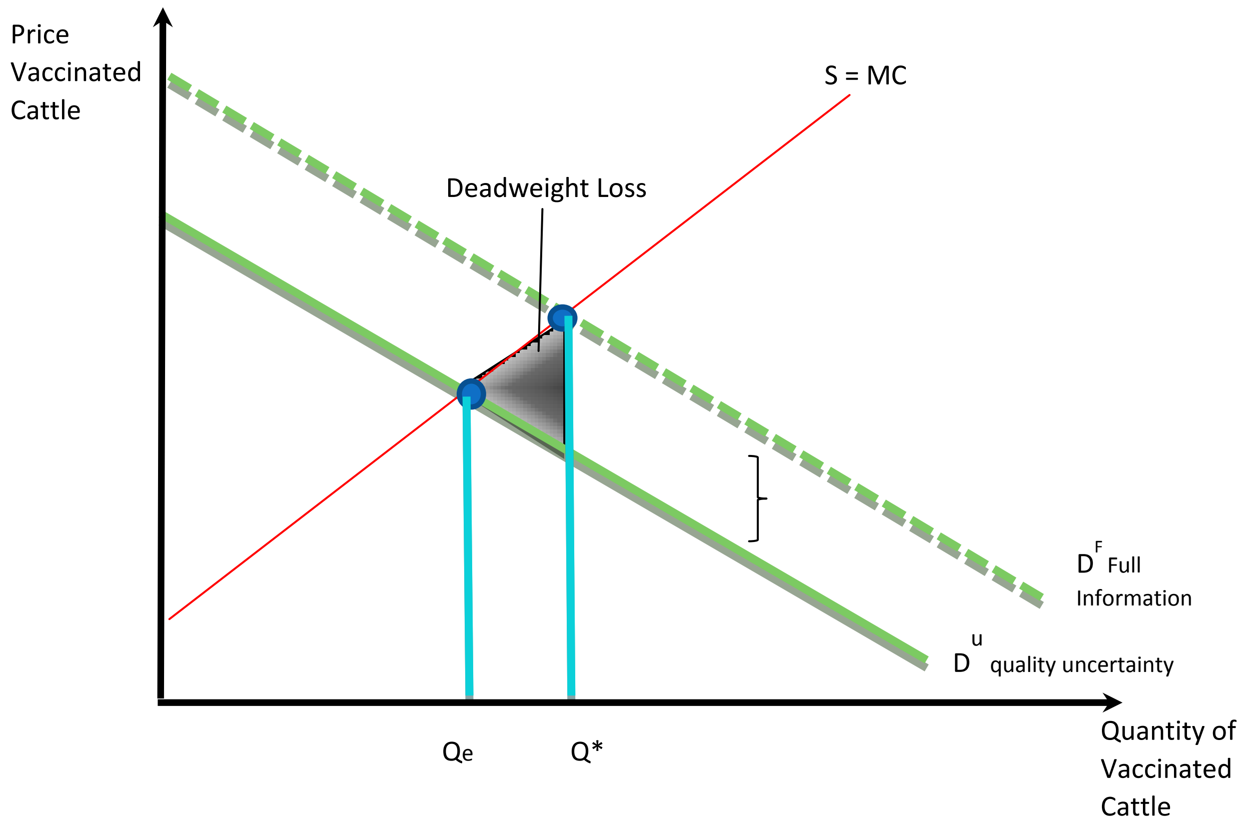

Figure 3. 3: Information Asymmetry and deadweight loss in the Vaccinated Cattle Market

The ultimate result from these different forms of market failure is one and the same. The logical response from producers regarding pre-harvest technology to aid in the reduction of E. coli in their cattle will be either under-investment or no investment at all. This holds true for the free-rider problem in the case of this technology that displays public good attributes, the positive externalities/spillovers that accrue to other parties, and lastly the classical conundrum of the market for lemons due to information asymmetry. This under-investment results in market failure which may warrant government intervention so as to correct the loss of efficiency within the market, provided that the benefits of intervention outweigh the costs.

3.3. Tragedy of the Anti-Commons

The theory of the Anti-Commons is premised on the notion that the right to exclude is greater than the right to use, thus leading to the under-utilization of a resource (Heller, 1997) and provides further insights into the underuse of the E. coli vaccine. In order for the E. coli vaccine to be significantly integrated into the beef industry, a threshold level of adoption is needed. In other words, in order for cattle producers who adopt the vaccine to benefit, other producers must also adopt the vaccine, otherwise incidences of E. coli contamination in the beef sector will not be lessened. Currently the non-adopters of this technology far exceed those that are willing to adopt. This follows from the three forms of market failure that were highlighted and discussed above.

Buchanan & Yoon (2000) suggest that the Tragedy of Anti-commons be measured in terms of the non-realized economic value due to the under-use of a resource considering that the size of such forgone opportunity is proportional to the number of exclusion right holders[7] involved. The authors note that the key factor to take into account in this case is the inefficiency that is imposed by each exclusion right holder on the willing participants and thus on society in general. Putting the above into the E. coli vaccine context, cow-calf operators that have currently chosen to enforce their exclusion rights by opting not to adopt the E. coli vaccine can be said to have capped the potential of those that are willing to adopt. This has led to low levels of adoption of this food safety initiative and losses to society at large.

Taking the explanation of Anti-Commons further, Parisi et al. (2003) suggest that this tragedy induces static (current) and dynamic externalities. They note that static externalities result from the current exercise of the right of exclusion by one or more owners, which nullifies the value of similar rights to use held by others. Furthermore, the authors suggest that dynamic externalities occur throughout time and are as a result of under-use of production assets in the present, bearing

[7] In the E. coli vaccine case, the exclusion right holders are those producers that are currently not willing to adopt.

consequences into the future in the form of penalties such as the XL Foods Inc. beef recall. The implications of this are such that the continued under-use of production assets such as the E. coli vaccine have the potential of causing recurring E. coli incidences in the beef industry.

Parisi et al. (2003), in their Anti-Commons argument, advocate that once a common resource (E. coli vaccine) is subject to multiple exclusion rights held by two or more individuals, the resource would not be utilized to its highest potential by these participants. The authors go on to note that the existence of a cluster of single owners seeking to exert their individual exclusion rights will cause the overall initiative to fall short of the net social benefits of the asset in this case in terms of its impact on the food safety improvement. This loss occurs simply because the multiple holders of exclusion rights do not fully internalize the cost created by the enforcement of their rights to exclude willing participants.

To put the tragedy of the Anti-Commons into the threshold perspective, suppose a portion of Canadian cattle producers decided to adopt the vaccine technology. After incorporating the technology as part of their pre-conditioning routine, the cattle are raised to slaughter weights in feedlots and eventually sold to packers. However, if the feedlot/packer also accepts cattle from producers who have not vaccinated their cattle, the reduction in the risk of contamination through cattle that are super shedders[8] is put in jeopardy. Thus, a certain threshold of adopters is needed to generate the potential industry wide benefits that can be created by such a technology.

Figure 3.4 below captures the Anti-Commons phenomenon from a cost perspective. Due to the presence of market failures, the right to exclude for cattle producers who do not wish to adopt the vaccine technology is greater than that of those who wish to adopt. Pictured in the graph, the marginal cost (MC) of a potential adopter increases relative to that of a non-adopter. This is due to identity preservation costs, third party certification costs, and search and information costs in arising from finding buyers interested in their vaccinated cattle. Furthermore, negotiation costs arise from attempting to secure contractual agreements for supply of their cattle, and finally general production and administration costs related to the vaccine are incurred. In the process of locating processors that can cater to their differentiated product, the aforementioned costs would be incurred as a means of distinguishing their products from unvaccinated cattle (the lemons

[8] Super shedders are cattle that exhibit higher levels of the E. coli bacterium in their rumens.

problem). These higher differentiation and production costs therefore have the potential of pricing the cattle producer off the market (point a in Figure 3.4).

Due to the various costs mentioned above, the price of the vaccinated cattle becomes very high relative to that of generic cattle to the point where potential buyers become uninterested. It should be noted that the MC would continue to rise as long as the pooling problem is in effect. In other words, E. coli vaccinated cattle shares the same supply chain with conventional beef products causing the continuous leftward shift in the supply curve. Linking the threshold perspective to that of the cost, once an optimal threshold is achieved, the aforementioned costs can be reversed back to equilibrium MC as shown in Figure 3.4. In other words, the right to use will be greater than the right to exclude if a favourable threshold could be achieved thus impacting on costs positively and ultimately increasing the demand for vaccines.

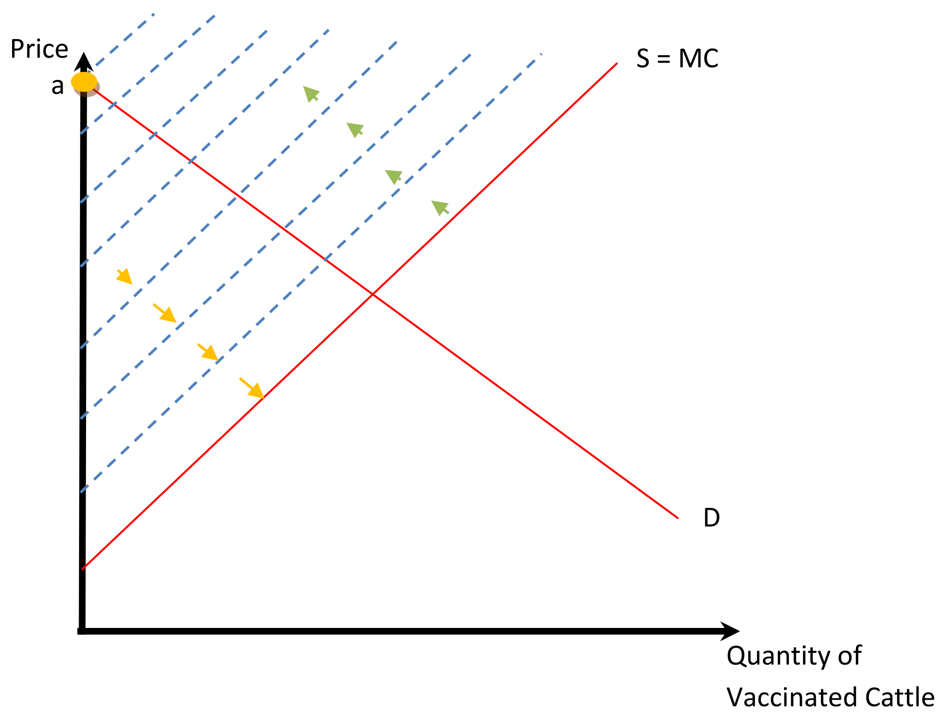

Figure 3. 4: Graph depicting the anti-commons phenomenon as it relates to cost

3.4. Transaction Cost Economics

Further insights are provided by Transaction Cost Economics (TCE) which, unlike the Neoclassical Economics framework, recognizes that there are costs that arise from exchanges across a market. Transaction costs arise between firms and affect the supply chain structures that emerge. Transaction costs include the costs of information search, negotiation, monitoring and enforcement. In the context of the E. coli vaccine, an adopter of the technology faces increased costs in relation to purchase and administration of vaccine; differentiation costs incurred as a result of preserving the identity of vaccinated cattle. If vaccinated cattle are pooled with non-vaccinated cattle in feedlots or by packers, the benefit of the cattle vaccine is reduced. The question thus arises whether packers will pay a premium for vaccinated cattle and the extent to which these cattle can be identified and segregated in beef supply chains. Supply chain governance structures that allow a value to be placed on the reduced risk from vaccinated cattle are necessary before a premium for these cattle will emerge. Closer forms of coordination such as through branded beef alliances or contracting may reduce the transaction costs of verifying vaccination programs.

Brocklebank et al. (2008) postulate that a rise in information costs is inevitable when supply chain participants fail to determine the presence of a particular attribute and thus spend resources finding other reputable supply chain partners. According to TCE, the governance structures that emerge are determined by the transaction costs facing buyers and sellers, thus as information costs increase due to the presence of credence attributes (vaccinated cattle), the cost of transacting through the spot market increases and supply chains are likely to become more closely coordinated. For example, this may entail introduction of vaccination requirements as a production protocol within a contract as part of a branded beef program.

The theoretical frameworks detailed above provide insights into the factors causing the low adoption rates of the E. coli vaccine and the potential changes to supply chain relationships that may be necessary to strengthen the market incentives for producers to adopt the vaccine. The market failure concept identified the E. coli vaccine as having public good attributes and positive externalities related to its usage by producers. Low rates of adoption are compounded by information asymmetry in distinguishing between vaccinated and non-vaccinated cattle in the absence of verification mechanisms. These insights help identify current barriers and incentives to adoption. Overall, the market failure concepts will assist in addressing the first and second objectives of this thesis: 1) Examine the underlying economics of incentives to adopt socially beneficial technologies and 2) explore the barriers that currently exist towards the adoption of the E. coli vaccine. The TCE framework allows for the third objective of this study to be realized by gleaning some insights into whether the incentives for adoption could be strengthened through closer forms of supply chain coordination, such as branded beef programs, as a means of rewarding the adopter of the technology by sharing the benefits from the technology adoption. The proposed methodology for addressing the study objectives is outlined in chapter 4.

CHAPTER 4

4. METHODOLOGY

4.1. Introduction

Emerging from the previous chapters is the need to examine the incentives that might encourage the adoption of socially beneficial technologies such as an E. coli vaccine amongst Canadian cow-calf producers. The factors that can influence a cow-calf producer's willingness to adopt are also of interest. The literature review in Chapter 2 implies that, like any other technology, there exist barriers and risk factors even if the technology has been shown to be fairly efficacious. Adoption therefore is dependent on the right conditions being met as was explained in Chapter 3 where various theories were used to shed some light on the challenges of adopting the E. coli vaccine. A survey of Canadian cow-calf producers is undertaken to explore these issues. This chapter explains the survey methodology, Best-Worst scaling (BWS) and other related approaches: Latent Class (LC) cluster analysis and the Binary and Ordered Probit model that are used to analyze the survey data.

The survey was designed to explore key areas such as the awareness and attitudes of cow-calf producers regarding their adoption of an E. coli vaccine; the management practices/interventions currently being exercised within their operations; the barriers that can lead to non-adoption and, the heart of the survey, the relative strength of different incentives to encourage adoption. The incentives and motivations are positioned as attributes in a stated preference experimental setting using BWS, rather than being examined using the typical method of asking respondents to rank the incentives in order of their importance (Likert-scale).

This chapter is structured as follows. First, an introduction to BWS and its application in a brief set of literature are discussed, followed by a description of scaling methods and BWS in sections 4.3 and 4.4 respectively. Section 4.5 introduces a conceptual framework and offers an empirical justification for BWS, followed by section 4.6 which describes the implementation of the BWS method and the design of the choice sets/tasks for the cow-calf producer survey used in this analysis. Data and analysis of BWS choice tasks together with the method for identifying BWS choice heterogeneity, are outlined in sections 4.7 and 4.8. Finally, analytical methods used to assess producer willingness to adopt and the empirical model specification used to analyze the data are explained, along with details of the modeling approach.

4.2. BWS Introduction

The major purpose of this chapter is to introduce the method of BWS, its application and its potential advantages in relation to alternative methods of examining the adoption of an E. coli vaccine. From the perspective of this study, the BWS approach is useful in examining the relative strength of various incentives for cow-calf producers to adopt an E. coli vaccine. It does so by probing the best (most influential) or the worst (least influential) among a set of incentives (attributes) presented in a series of repeated choice sets.

A relatively novel but sophisticated attribute-based method of stated preference, the BWS approach is used to examine the influence of a set of incentives in a way that would allow the greatest of discrimination through multiple sets of attribute trade-offs. BWS is also effective at reducing any biases that have previously distorted the analysis of survey data, as will be discussed in the scaling methods section. The best-worst scaling method has been used in a range of disciplines, particularly in health and consumer marketing, with relative success. In addition, BWS in conjunction with Latent Class cluster analysis has also been used in various agri-food applications, as captured by the brief literature review below.

Best-Worst Scaling is a stated preference based method that allows surveyed respondents to choose the “best” and “worst” attributes in a repeated number of choice sets, in this case, incentives to adopt a specified management technology. These best and worst choices are subsequently counted according to a realizable scale that is dependent on the number of times each of the presented attributes appears in the total choice sets. The count information is then transformed into BWS scores which signal the relative importance of each attribute presented in the available choice sets. For more details on the calculation of the BWS score, see the analytical method sub-section 4.7.2. Erdem and Rigby (2013) note that BWS is specifically used for ranking a large number of items with respect to their importance or preferability to individuals. Sackett et al. (2013) on the other hand note that it requires survey respondents to choose the most important and least important attributes from a set of competing options simultaneously; the major benefit to the researcher being the simplicity of analysis (Goodman et al., 2005).

4.3. Scaling Methods

According to Cohen (2009), one form of a rating scale is the Likert-type scales where subjects are typically asked to rate each attribute on a preference rating scale. The author notes that sometimes each response category is labeled and at times only the endpoints are indicated; descriptors such as (e.g. "important", "not important", "good" or "fair") are often used to label scale categories. Crask and Fox (1987) suggest that one issue regarding scaling methods is that survey respondents are not inclined to use the ratings provided in the same way across respondents, and thus, the meaning respondents tend to associate to categories influences the perceived distance between categories. They note that the distance between four and five for one individual may be different to that of another individual.

Goodman et al. (2005) posit that unless one alternative or attribute clearly dominates, it is rather difficult to identify the most important attribute or the most preferred product. Thus, treatment of category ratings as equal interval scales has the potential to generate different conclusions than if they are treated as ordinal scales. The authors note that oftentimes these differences are statistically significant and emphasize the difficulty of assessing whether the rating of 5.7 out 7 is meaningfully different from 5.1 out of 7. A subsequent issue with respect to rating scales is that each attribute is frequently measured with a single item rating scale specifically developed just for that particular survey, thus the reliability and validity of the scale is unknown outside of that study sample.

Finn and Louviere (1992) state that assessing attribute importance by rating scales is usually not measured relative to other attributes thus making such responses unable to provide adequate discrimination to help managers identify real priorities. Following this, the relative importance of each attribute is then derived based on the averages determined across all respondents, thus, it is not possible to draw reliable conclusions concerning the importance of issues or attributes as there is no possibility for respondents to make trade-offs between the attributes (Cohen, 2009).

Another method used to evaluate the relative importance of attributes that warrants discussion is ranking. This method requires respondents to rank attributes in terms of a specific characteristic, in this case, for example, ranking incentives for adoption of the E. coli vaccine by importance. Cohen (2009) notes that this task is considered relatively easy for respondents to complete if the number of attributes is small, however, as the number of attributes increases the task becomes exhausting for respondents. The author goes on to state that the ranking task could be simplified further by using paired comparisons (developed by Thurstone, 1927) due to its ease of use and reliability. In this method, respondents are asked to choose which is "more" important (the other being the "less" important) of the two items that are presented. Assuming n items, Cohen (2009) suggests that the number of possible pairs would be n (n-1)/2, thus highlighting the disadvantage of the paired comparison: the number of pairs required to be judged rises as the number of items increases. For example, for 10 items one would need 45 pairs to be compared, with 13 items we need 78 pairs and for 16 items the number of pairs would be 120 (Cohen, 2009).

An effective way to overcome the exponential increase in the number of subsets is to divide the items in manageable subsets of three or four items each and ask the subject to order the items in each subset in terms of importance. This has the opposite effect, as the number of items in each subset increases, the number of subsets decreases, for example, if one wants to compare 13 attributes and use subsets of four items in each subset, only 13 subsets will be required if a balanced incomplete block design (BIBD) is incorporated (Cohen, 2009). Rather than ranking four items in each choice set, one can choose the most preferred item ("best") and the least preferred item ("worst") making the BWS method an extension of the paired comparison. Best-worst scaling according to Goodman et al. 2005 (p.4) "models the cognitive process by which respondents identify the two items with the most and the least of a characteristic from designed subsets of three or more items." Furthermore, the authors note that this method has several advantages that overcome the limitations of other methods of measurements such as rating-based methods as discussed above.

Discrete choice experiments are also fairly common in the literature, where attributes are presented in various combinations and respondents are asked to make trade-offs between the choice sets. Cohen (2009) notes that although this method allows preferences for new attributes and combinations to be assessed, a strength of the method, it has a number of disadvantages.

One of the disadvantages of discrete choice experiments is that the design and analysis is complex and requires the use of highly sophisticated computer software. Moreover, another more serious limitation noted by Louviere and Street (2000) is the difficulty of interpreting the data including the inability to compare utilities across different experiments. Best-worst scaling is therefore well placed to address some of the concerns experienced with other survey methodologies.

The choice of BWS was informed by a review of alternative stated preference methodologies and an assessment of their relative strengths and limitations with respect to the research questions posed in this thesis. According to Louviere et al. (2010) grey literature suggests that hundreds, if not thousands of research projects in varying forms of surveys have been carried out by academics and practitioners alike throughout the world with the intention of capturing people's subjective views and opinions, attitudes and perceptions, and value systems. The authors indicate that the majority of these surveys and research projects utilize rating scales, with a substantial majority having preference for methods such as paired comparisons or ranking (sorting, etc.), or "pick-any" methods to elicit data from individuals and groups about subjective quantities.

The Best-Worst Scaling approach was developed by Louviere and Woodworth (1990) and first published in 1992 by Finn and Louviere. Recent pertinent studies that have utilized the best-worst scaling method include Erdem and Rigby (2013) who used BWS to elicit the levels of control respondents believe they have over risks and the level of concern those risks prompt. The surveyed sample comprised members of the general public, 166 from rural areas including farmers and 114 urban respondents. Twenty risks were included as attributes in the BWS survey, with half concerning food hazards such as E. coli, Salmonella, additives and BSE while the rest covered non-food hazards such as being burgled, struck by lightning and climate change. The BWS approach was useful in this particular study as the authors sought to capture perceptions of control and concern over a variety of risks. This elicitation method as noted by the authors is structured to allow a reduction in the cognitive burden typically associated with ranking large sets; the approach permits derivation of individual-level values or scores.

Cross et al. (2011) adapted the best-worst scaling method to elicit experts' assessment of the relative practicality and effectiveness of measures to reduce human exposure to E. coli *O157:H7*. The authors examined a total of 30 interventions grouped into 12 sets, with each set containing five measures and the various combinations of the sets having been determined by an experimental design. These attributes in the form of measures included: cattle vaccination, hand-washing, usage of probiotics and the removal of high shedding animals prior to slaughter to mention but a few. The use of BWS proved to be a powerful tool according to the authors as it broke down an otherwise cognitive demanding process into simple, repeated and manageable tasks. Moreover, statistical analysis of the resulting data provided a scaled set of scores for the measures, as opposed to just a ranking.

An example of a BWS study run concurrently with a LC cluster analysis is that of Umberger et al. (2014) who examined the relative importance of various buyer characteristics (attributes) to small potato farmers in Indonesia. Examples of these attributes included: pays cash immediately, provides price premiums, established relationship, and always follows through on commitments to buy my product, to mention a few. A Latent Class cluster analysis is used to explore whether producers' utilities (preferences) for marketing channels are heterogeneous; the results of the study found existence of four unique classes/segments of producers. Latent Class cluster analysis involves using cluster software to find differences in decision making patterns among respondent data and grouping respondents with similar patterns into unique classes/segments.

Another method that is used to analyze other aspects of the cow-calf producer survey is the Binary and Ordered Probit models which are used to determine the factors that can affect a producer's willingness to adopt (WTA) an E. coli vaccine. In the survey developed for this thesis, the question that was used to capture the WTA was presented in the form of an anchor: would you consider adopting an E. coli vaccine if presented with the right incentives? (See appendix: question 27 of survey for full details). Presenting this question in anchor form created a variation of what the literature refers to as an anchored BWS. This question would normally be asked after each of the presented choice sets as a means of capturing extra information from the respondent regarding the attributes presented within the choice sets.

4.4. Best -Worst Scaling

Best-Worst Scaling takes three forms, divided into three main categories: BWS case 1, case 2 and case 3. Louviere et al. (2012) note that the frequent lack of clarification in a myriad of published articles as to which case is being used reflects the fact that different disciplines have tended to embrace different cases. For this particular research, case 1 of the BWS was deemed to be appropriate to capturing the importance of various incentives for E. coli vaccine adoption. Case 1 BWS is considered to be suitable when the researcher is interested in the relative values associated with each item in a list objects (Louviere et al, 2012); see Table 4.1 below as an example. Case 2, as noted by Adamsen et al. (2013) cited in (Potoglou et al. 2011, p.4), has primarily been used in valuation studies concerned with general population preferences, such as quality of life attributes. The authors state that it is generally acknowledged that this approach is most appropriate when respondents have no experience with choice making in the particular area of investigation, therefore warranting profiles to be presented one at a time, contrary to case 3, as seen in Table 4.2. Table 4.3 below shows multiple profiles that are utilized in case 3. It should be noted that the emphasis here is not so much on the contents in the tables but on the structure and the presentation of information contained within the tables.

Louviere et al. (2012), in explaining case 1, further suggest that the objects might take the form of brands, public policy goals, or any set of objects that can be meaningfully compared without the consideration of a level structure (e.g. colour as an attribute (object) with levels presented as: blue, green and orange). Moreover, since there is no level structure to consider, case 1 designs are typically less complex (and less problematic) as compared to other stated preference survey methodologies, such as Discrete Choice Experiments (DCEs). Adamsen et al. (2013) posit that the main differences between case 1 and the other BWS cases is that case 1 study objects (which might be an attribute or profile) are simply presented as stand-alone measures and evaluated as such, whereas in cases 2 and 3 studies attributes are bundled into a product or service as captured in Tables 4.2 and 4.3. Furthermore, cases 2 and 3 focus on the different levels that an attribute may contain which are then presented in a bundled format so as to elicit responses from survey participants.

Table 4.1: *An example of case 1 BWS (adapted from Flynn, 2010)*

BWS Case 1 **Please consider you are out shopping and want to buy apples. Tick which attribute is most and least important to you.**		
Best/Most		Worst/Least
	Production Method	
	Price	
	Packaging	
	Appearance	

Table 4.2: *An example of case 2 BWS (adapted from Flynn, 2010)*

BWS Case 2 **Please consider you are out shopping and want to buy apples. Tick which apple is most and least important to you.**
Apple 1
Organic
AU$8.99/kg
Packaged
B-grade
Best ☐
Worst ☐

Please consider you are out shopping and want to buy apples. Tick which apple is most and least important to you.
Apple 2
Conventional
AU$6.99/kg
Packaged
A-grade
Best ☐
Worst ☐

Table 4.3: *An example of case 3 BWS (adapted from Flynn, 2010)*

	BWS Case 3 **Please consider you are out shopping and want to buy apples. Tick which apple is most and least important to you.**	
Apple 1	**Apple 2**	**Apple 3**
Organic AU$8.99/kg Packaged B-grade	Conventional AU$6.99/kg Packaged A-grade	Organic AU$7.99/kg Loose-weight A-grade
Best ☐	**Best ☐**	**Best ☐**
Worst☐	**Worst☐**	**Worst☐**

The BWS method assumes that there is some underlying subjective dimension, such as "degree of importance" or "degree of interest" and the researcher wishes to measure the location of some sets of objects along this dimension (Auger et al., 2004). In this thesis, the underlying continuum is "degree of influence" and the objects are the various incentives that can potentially influence adoption of a socially beneficial technology (an E. coli vaccine). This method is commonly referred to as "maximum difference scaling" since the attributes chosen are designed to maximize the difference in utility realized by a respondent on an underlying scale of preference. In addition to the "best" information, the collection of the "worst" information ensures that BWS respondent's choices of the top and bottom objects in a set, ceteris paribus, are more reliable and valid than choices of middle objects (adequate discrimination) (Louviere et al., 2013).

Sackett et al. (2013) state that the measured level of importance from the best-worst data analysis is applied to a standardized ratio scale that determines the percentage difference in importance across attributes with more certainty. Additionally, selection of best and worst items also provides sufficient information to calculate the preference scores of each survey respondent, allowing heterogeneity of responses for individual items to be assessed (Jones et al., 2013).

Sackett et al. (2013) note that BWS is capable of addressing relative impacts on utility across attributes that customary discrete choice questions cannot, given the level of discrimination BWS allows through multiple trade-off opportunities. The authors argue that for one to observe the trade-off behaviour in a BWS model, the repetition of the specific attributes from a choice set of competing alternatives is necessary over a number of variable choice sets. Following from this, the best-worst tasks would provide more information than single choice designs whilst simultaneously forcing respondents to consider the extremes of their utility space (Sackett et al., 2013). Erdem and Rigby (2013) state that the models estimated on best-worst data sets are probabilistic in nature and thus inconsistencies (such as violations of transitivity) within the ranking process are not inconsistent with the analytical approach. They note further that increasing the frequency with which items are seen helps reduce the impacts of such occasional violations.

Another motivation for the use of BWS is that the choice task is thought to be more manageable and easier to complete for respondents compared to tasks where respondents are asked to rank full sets with Likert scales (e.g., strongly agree to strongly disagree or 1 to 5, with 1 being not important and 5 very important) (Auger et al., 2004; Cohen and Markowitz, 2002; Finn and Louviere, 1992). Furthermore, Cohen and Orme (2004) suggest that there is evidence that people use better judgment when they only need to evaluate extreme preferences rather than preferences in levels. Thus identifying preferences with levels can be problematic due to the different uses and open interpretation of the rating/ranking scale which may potentially cause biases (Cohen and Markowitz, 2002). Cross et al. (2012), Finn and Louviere (1992) and Marti (2012) indicate that BWS avoids biases such as scale bias and provides improved discrimination between items. The BWS approach therefore may reduce or even avoid these problems because the terms “most” and “least” are less open to variation in interpretation (Erdem and Rigby, 2013).

In addition to the above mentioned potential advantages, the BWS process generates data conducive to estimation using well-established econometric models that improve accommodation of heterogeneity, in both preferences and error variance, through estimation of, inter alia, Latent Class, Random Parameter, and error component Logit models (Erdem and Rigby, 2013).

4.5. Conceptual Framework for Best-Worst Scaling

Louviere et al. (2013) note that the basic tenets of the best-worst scaling method are underpinned by Random Utility Theory (RUT), as with other methodologies such as DCEs. This theory assumes that an individual's relative preference for an object A over object B is a function of the relative frequency with which object A is selected as a preferred choice to object B. Louviere et al. (2013) summarize the above as a theory that requires individuals to make choices stochastically (with some error).

Thurstone (1927) proposed the use of RUT, which served as motivation in developing the method of paired comparisons where individuals are faced with the task of choosing the "best" object from sets of two objects given the objective of uncovering an individual's relative preference of one preference over another Louviere et al. (2013), alluding to Thurstone, recognized that the RUT theory is dependent on individuals making errors in their choices, so that it is possible to derive the model parameter estimates that are known as "scale values." The authors define scale values as measures of the locations of each object on an underlying subjective scale of interest. Following Thurstone (1927), McFadden (1974) was successful in generalizing Thurstone's RUT model yielding more tractable closed-form models, which have the capability of accommodating choices from sets of three or more objects. Formally illustrated, the "best" only case by McFadden is shown in the choice set below with attributes A, B, C and D; S referring to the true but unobservable subjective quantities of each of the attributes.

$S_A = V_A + E_A$

$S_B = V_B + E_B$

$S_C = V_C + E_C$

$$S_D = V_D + E_D \qquad (4.1)$$

The true subjective value (S_K) of the K_{th} object consists of two components as seen above, the observed value V_k which is considered to be systematic (explainable) in nature and the error term E_k which is random (unexplainable). McFadden (1974) notes that the random component implies that one cannot predict the exact choice that a person will make, but rather, only the probability that a person will choose each object offered. The choice probability can be expressed as follows:

$$P\,(A = \text{best} \mid A, B, C, D) = P\,[(V_A + E_A) > (V_K + E_K)] \qquad (4.2)$$

Considering all other options that are available to be chosen in the comparison set, the probability of attribute A being selected as preferred from the entire choice set is equivalent to the probability of the unobservable subjective value of attribute A being greater than the subjective value of all the other options. McFadden (1974) was able to derive what is commonly known today as the Conditional Logit model by making the assumption that the error terms displayed above operate as independent and identically distributed (I.I.D) Type 1 extreme values.

Turning to the present project, in similar style to Erdem and Rigby (2013), we use the RUT to model decisions, views or opinions (i.e. perceptions of importance of incentives for the adoption of an E. coli vaccine), rather than the usual maximization of utility from a good or service. The major idea here is that a producer is going to select incentives that maximize his/her level of satisfaction in terms of the perceived desirability of different incentives to adopt this technology. A simplified Random Utility Model can take the following form:

$$U_{ij}, t = B_i X_{ij}, t + E_{ij}, t \qquad (4.3)$$

Where, U_{ij}, t is individual i's utility from his/her selection of alternative j in a choice set t = {1, 2,…K}, B_i is individual i's utility parameter vector, X_{ij}, t is a vector for attributes (incentives) associated with alternative j, and E_{ij}, t is the stochastic (random) component, which allows researchers to make probabilistic statements about respondents' behaviours, in our case producers' choice behaviours, as suggested by Adamowicz et al. (1998) and Lusk (2003).

The major idea here is that a respondent will choose a pair of attributes (i.e. incentives) that maximize the utility differences in his/her best and worst choices. Let's assume that the respondent chooses incentive j over incentive k, as the best and worst, respectively, out of a choice set with J items. The probability then that respondent i chooses incentive j over incentive k is the probability that the difference in utility U_{ij}, t and U_{ik+}, t is greater than all other J (J-1)-1 possible differences in the choice set (Louviere et al. 2013). Assuming E_{ij}, t is distributed I.I.D Type 1 extreme value; this probability can be expressed in a simple Logit form as follows:

$$\text{Prob (j is chosen best and k is chosen worst} = \frac{e\ Uij,t-Uik,t}{\sum_{L=1}^{J}\sum_{M=1}^{J} e\ Uij,t-Uim,t} \qquad (4.4)$$

To recall, one of the reasons best worst scaling is considered as a useful method of evaluating survey responses is its ability to transform the best and worst scales into ratios that are equivalent to the multinomial Logit estimates. The next section delves into the implementation of a Best-Worst experiment.

4.6. Implementing Best-Worst Choice Tasks

4.6.1. Design

Louviere and Woodworth (1990) suggest that one of the key issues of implementation is to design a series of choice sets that include all of the items/objects identified by the researcher and all the possible comparisons an equal number of times for each respondent. A statistical/experimental design to construct the choice sets in the form of a balanced incomplete block design was utilized in the cow-calf producer survey to meet that standard. The BIBD was used to design the comparison sets since BIBDs can arrange attributes as efficiently as possible, reducing the number of sets that are required to obtain information about the importance of the attributes (incentives) selected with minimum loss of statistical information (Burke et al. 2013). The outcome of such a design is that each of the incentives occurs equally often and in a controlled number of times with each other. According to Louviere et al. (2012) a BIBD, in ensuring that occurrences and co-occurrences of attributes is constant, also helps in minimizing the chance that respondents can make unintended assumptions about the attributes based on aspects of the design. An example is if an attribute occurs within the choice sets more than the others, the respondent might select it on the conclusion that the attribute is more favoured by the researcher, thus causing social desirable responses on the part of the survey respondent.

A BIBD was applied to the incentives identified in Table 4.4 below. In a similar approach to Cohen (2009), a BIBD design for v attributes denoted as (b, r, k, λ) was adopted, where b is defined as the number of choice sets (blocks), r is the repetition per level, k is defined as the number of attributes appearing in each choice set (block size) and λ the pair frequency.

In the context of this study the BIBD takes the form (13,4,4,1), where V = 13 incentives yielding 13 choice sets, each incentive appearing 4 times across all the available blocks, each choice set containing 4 incentives and each incentive compared once with each of the other incentives. The result of the BIBD of the 13 attributes (incentives) is shown in Table 4.5 below. Each of the 13 choice sets were presented as separate tables/choice sets in the producer survey (see survey question 26 in Appendix 1), with the number of the attribute substituted with its description as per Table 4.4.

Based on the review of literature, key issues drawn from the discussion of theoretical considerations, and interviews with cow-calf producers and industry participants, 13 attributes deemed to be suitable incentives in influencing producer decisions to adopt the E. coli vaccine were chosen. These attributes (incentives) are presented in Table 4.4. These incentives can be subdivided into several categories: government intervention related incentives, market/supply chain incentives, production protocol related incentives; producer reputation incentives; and other.

Table 4.4: *Attributes (Incentives)*

Identified Attributes: Incentives for E. coli Vaccine Adoption[9]
Government Intervention Incentives
Government recommending use of E. coli vaccine for cattle **(Government recommendation) (3)**
Subsidy to compensate the costs of my adoption of the vaccine is available through a government vaccination program **(Subsidy to compensate costs) (10)**
Market/Supply Chain Incentives
Premiums for E. coli vaccinated cattle are available through various programs (branded beef program) within the supply chain **(Premiums for E. coli vaccinated cattle available) (2)**
Attraction of *a new set of buyers* for my vaccinated cattle **(8)**
My buyer requiring use of vaccine as part of the production protocol as a condition for accepting my calves/cattle **(My buyer requiring use of vaccine) (11)**
Feedlots providing an assurance that they will give my cattle a booster of the E. coli vaccine to maintain the immunity of my cattle **(Feedlots providing booster assurance) (6)**
Through vaccination, my farm is less exposed to the effects of E. coli outbreaks, such as beef recalls and *supply disruptions* at packing plants **(Less E. coli exposure due to vaccination) (13)**
Production Protocol Incentives
Recommendation from my *veterinarian* to use the E. coli vaccine in my operations ***(Recommendation from Veterinarian)*** **(4)**
I can include an E. coli vaccination in *my existing vaccination routine* ***(Inclusion of vaccine in existing vaccination routine) (7)***
Duration of immunity for my calves/cattle is greater than six months **(12)**
Producer Reputation Incentives
Beef products from my calves/cattle can be *traced* back to my farm/operations **(Traceability to farm) (1)**
My reputation for a cattle producer is at risk because of higher consumer expectations concerning food safety **(Reputation as producer is at risk) (5)**
Other
My neighbours (other cattle producers) are adopting the E. coli **vaccine (Neighbours adopting E. coli vaccine) (9)**

[9] The numbers included in brackets after each incentive refer to the attribute numbers presented in Table 4.5.

Table 4.5: Balanced Incomplete Block Design *(Adapted from Cohen, 2009)*

V = 13 Choice set no.		(13,4,4,1) Attribute no.		
1	1	2	4	10
2	2	3	5	11
3	3	4	6	12
4	4	5	7	13
5	5	6	8	1
6	6	7	9	2
7	7	8	10	3
8	8	9	11	4
9	9	10	12	5
10	10	11	13	6
11	11	12	1	7
12	12	13	2	8
13	13	1	3	9

4.6.2. Justification of Attributes (Incentives)

Government Intervention related Incentives

The first category involves government recommendation (attribute 3) and subsidy to compensate costs (attribute 10) in Table 4.4. These incentives are included on the premise that a situation of market failure makes government intervention a potential action in correcting the deadweight loss (DWL). This intervention is however dependent on the benefit of intervention outweighing the cost. In this case, the potential market failure comes in the form of information asymmetry and public good/positive externalities from possible adoption of the E. coli vaccine as discussed in Chapter 3. The expectation that cow-calf producers should be compensated for costs of adoption is derived from the market fundamentals of welfare economics particularly through the compensation principle in the event that the Pareto principle cannot be achieved i.e. a second-best option. Government intervention could also take the form of strong recommendation, particularly in the case where public safety is a concern in relation to E. coli incidences, as captured by attribute no.3 where government recommends use of the vaccine.

Market/Supply Chain Incentives

The market/supply chain attributes (incentives) shown in Table 4.4 include: premiums for E. coli vaccinated cattle available, my buyer requiring use of vaccine, feedlots providing booster assurance, and less E. coli exposure due to vaccination. These incentives are relevant for cow-calf producers if the adoption of an E. coli vaccine has the potential to create product differentiation in the form of a value chain for vaccinated cattle, where private labels and brands generate higher margins for an assured supply of vaccinated cattle and beef with lower risks of E. coli. Thus, these attributes allow an assessment of the extent to which the availability of premiums or access to differentiated supply chains incentivizes producers to adopt the vaccine. Furthermore, such incentives may also have the potential of reducing the chances of beef recalls and any disruptions to cow-calf producer access to markets for their calves.

Production Protocol Incentives

The extent to which including the E. coli vaccine in already existing production protocols affects incentives to adopt is captured by recommendation from veterinarian (attribute 4) and less E. coli exposure due to vaccination (attribute 7) in Table 4.4. The idea here is that if producers incorporate this technology/innovation into their already existing preconditioning process, this would lower their cost of adoption. These incentives tie back to the notion of scale of change introduced in the literature, where the perception of a larger scale of change may serve as a barrier to adoption. In addition, these incentives also capture vaccine efficacy concerns. A key issue for most cow-calf producers that was uncovered in the pre-survey interviews was the duration of immunity captured by attribute 12. Based on industry interviews, it is expected that a duration of 6 months or greater is preferred in order to preserve producer efforts through to the next stage of the production process.

Producer Reputation Incentives

Reputation is a key element in any business operation. Therefore, if traceability mechanisms are created within the supply chain, such that in the event of an E. coli outbreak the contaminated beef can be traced to its point of origin, producers may be inclined to take extra measures to ensure their output is safe and secure for the consuming public. For this reason, two reputation based attributes were included: traceability to farm (attribute 1) and reputation as producer is at risk (attribute 5) as seen in Table 4.4. In the literature, Pouliot and Sumner (2008) introduced traceability and liability as motivating factors in the adoption of food safety controls.

Other

Neighbours adopting E. coli vaccine (attribute 9) captures the social network within which producers operate. This social network influences the practices within their operations, as discovered by Ellis-Iversen (2010) who assessed the role of veterinarians serving as motivators in the adoption of zoonotic measures. Thus, if a producer's neighbours are adopting the technology and they share their experience with the producer, his/her learning curve may be reduced. This attribute ties back to the Anti-Commons argument developed in Chapter 3, where a particular adoption threshold would need to be met to encourage greater producer participation.

Following is an example of a choice set: choice set no. 7 in Table 4.5 (attributes 7, 8, 10, and 3) presented in Table 4.6 below. Respondents of the survey were provided with 13 randomized choice sets with different combinations of incentives to assess.

Table 4.6: *An example of a BWS Choice set as presented in the survey*

	Following from the scenario above, for each of the following tables, tick (click) the ONE incentive that will MOST influence your choice of adoption and the ONE that will LEAST influence this decision.	
Most Influential (select only one)	**Of these incentives, which would be Most likely to influence and Least likely to influence your adoption of an E. coli vaccine...**	Least Influential (select only one)
○	I can include an E. coli vaccination in my existing vaccination routine.	○
○	Attraction of a new set of buyers for my vaccinated cattle	○
○	Subsidy to compensate the costs of my adoption of the vaccine is available through a government funded vaccination program.	○
○	Government recommending use of E. coli vaccine for cattle	○

4.7. Data and analysis of BWS choice tasks

4.7.1. Data collection

An online survey of Canadian cow-calf producers was used to gather data for this study. Prior to contacting participants, approval from the University of Saskatchewan Behavioural Research Ethics Board was obtained.[10] A market research company (Ipsos Agriculture and Animal Health) was commissioned to administer the survey, given the geographical coverage of the sample and the target audience. This sample was drawn from Ipsos animal health/producer database. The survey was conducted in July 2014, where pre-tests of the online version of the survey were done in mid-July on approximately 20 cow-calf producers to determine whether any changes to the

[10] Approval was granted on June 27, 2014 (University of Saskatchewan Behavioural Research Ethics Board BEH # 14-136).

survey were needed. Finally, a full launch of the survey was performed towards the end of July that targeted cow-calf producers in the provinces of Alberta, Saskatchewan and Manitoba. These provinces were selected as they represent the largest share of the beef cow population in Canada at 40.7%, 29.8% and 11.6% respectively (Figure 4.1).

Initial paper drafts of the producer survey were pre-tested in person through interviews with cow-calf producers from various locations in Saskatchewan. Furthermore, draft surveys were e-mailed to willing pre-testers which included industry experts who were not available face to face. Based on the feedback received from the pre-tests, a refined paper version of the producer survey was further pre-tested on other cow-calf producers in Saskatchewan. Minor modifications were then made before the survey was formatted into a final online version to be administered to cow-calf producers. The pre-test and re-test phase was necessary to ensure that the survey was understood by intended respondents, well-designed, and capable of answering the research questions presented in Chapter 1.

Although internet surveys have been known to create some sampling biases in terms of the demographic structure (older, less wealthy and less educated individuals), the growth and proliferation of internet access across Canada lessens such concerns. Statistics Canada (2012b) quotes internet use within the general population as 83 percent in Canadian households. Given that this study sought to survey a sample of cow-calf producers, an internet based survey was well placed to harness the geographical diversity of the sampled group.

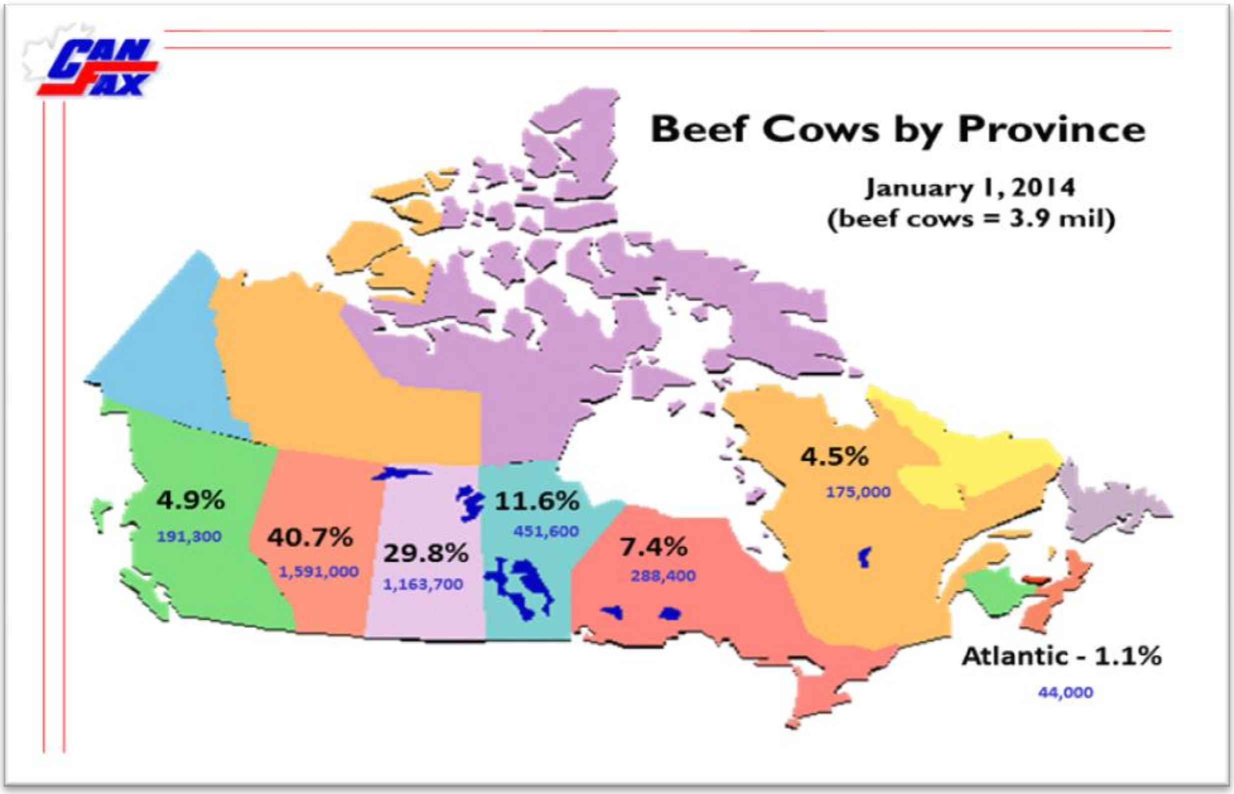

Figure 4. 1: Beef cow population by Province

Source: *(Canfax)*

Furthermore, an online-based survey proved to be advantageous from the perspective of reducing potential missing values in critical aspects of the survey. In the BWS section respondents were required to respond to all of the choice sets[11]. Cohen (2009) notes that using online surveys compared to paper questionnaires helps avoid missing data points due to respondents not completing the choice sets as intended. The author argues that online surveys also allow randomization of choice sets, which is a complex task using paper questionnaires. The choice sets in the cow-calf producer survey were randomized across respondents to eliminate any familiarity or pattern bias.

[11] It should be noted that an exit option was available such that respondents could opt out of the entire survey at any time. The final number of observations includes only fully completed surveys.

The survey consisted of four main sections (see Appendix 1 for the full survey). First, information was gathered about the cow-calf operation, such as the respondent's primary role on the farm and marketing channels used. Second, an awareness and information section assessed cow-calf producers' knowledge and perceptions towards the E. coli *O157:H7* pathogen and the E. coli vaccine (survey questions 6-19). Furthermore, management interventions/practices in use to reduce or mitigate E. coli incidences on the farm/environment were examined (question 24). In the next section, a best-worst choice task experiment was presented whereby cow-calf producers were asked to choose the "best" and "worst" incentives to adopt an E. coli vaccine from a series of 13 choice sets, each containing four incentives. The implementation of the best-worst choice task was explained in section 4.6 above. This section was designed to assess the relative importance of each incentive to cow-calf producers.

Third, questions on the barriers to the adoption of the E. coli vaccine, such as costs, uncertainty about benefits of adoption etc. (see question 28) were examined. Locus of control[12] questions followed (see question 29) which evaluate the locus of control of individual respondents with respect to both their cow-calf businesses in general and the management of E. coli risks in particular. Examples of questions used to capture the internal and external locus of control included: "whether or not I'm successful in mitigating/controlling E. coli depends mostly on my own ability"; "to a great extent E. coli incidences on my cow-calf operation are determined by factors beyond my control" respectively. These questions sought to measure the internal locus, the belief that one's own ability, effort, or actions determine what happens on the farm and the external locus, the belief that fate, luck or outside forces are responsible for what happens within the farm environment. The inclusion of a locus control section in surveys is explained by Spector (1982), who notes that locus of control may moderate the relation between incentives and motivation and between satisfaction and turnover in his assessment of behaviour in organizations as a function of employees' locus of control.

[12] This variable was measured using a Likert scale, with 1 representing complete disagreement and 5 complete agreement. See chapter 5 for a more detailed explanation of the measurement of this variable.

Lastly, socio-demographic questions were included: respondents' gender, age, highest level of education, years of experience in the cow/calf sector, how long they intend being in the cow-calf business, and the importance of the cow-calf operations to their livelihood. These questions allow for sources of heterogeneity in the responses to best-worst questions to be assessed.

4.7.2. Analytical Method

The BWS component of the data/survey was designed to ensure that each incentive appeared 4 times across all the choice sets (see Table 4.4 above). As noted earlier, the simple difference in BWS scores, i.e. taking the number of times an item is considered "best" and subtracting the number of times it is considered "worst" is a close approximation of the true scale values: the scales values obtained through Multinomial Logit analysis (Marley and Louviere, 2005). Such properties allow for a swift and simplified investigation of the relative value of a specific object by scaling the number of times the object is considered "best" against the number of times the object is considered "worst".

In the analysis of BWS data, in order to determine the level of importance for each of the incentives, the number of times an incentive was selected as least important (worst) was subtracted from the number of times it was chosen as the most important (best) for all 13 attributes for each respondent. The outcomes of these calculations are individual level scales for each of the 13 incentives. The level of importance of each attribute depends on the number of respondents and the frequency that each attribute appears in the choice sets, as per equation (5) below. As each of the 13 incentives appeared a total of four times in all the presented choice tasks, the individual level scales for each of the incentives can only range from + 4 to – 4. As noted by Cohen (2009) frequencies beyond this range indicate error(s) in the data.

For example, a value of + 2 could be obtained if a survey respondent chose an incentive as most desirable three times and selected the same incentive once as least desirable. Positive values of best-worst indicate that the particular incentive was more frequently chosen as best; while negative values suggest that the incentive was more often selected as worst. The level of importance/influence of a particular attribute/incentive was transformed into a standard score, following Goodman et al. (2005) who note that the reason for such standardization is to allow comparison between different groups of respondents. Below is a simple formula showing how the best-worst outcomes are transformed into standard scores for each attribute.

$$\text{Standard Score} = \frac{Count\ (Best) - \ Count\ (Worst)}{4n} \tag{4.5}$$

Where:

Count (best) = total number of times an incentive was most important

Count (worst) = total number of times an incentive was least important

N is the number of questionnaires/observations

4 is the frequency of the appearance of each incentive in the design

Further to this standardization, in order to determine the rank ordering of the incentives in terms of their relative importance and, following Marley and Louviere (2005), a "maximum difference" scale that is simply the difference between the "best" and "worst" columns is calculated. Another approach to enable comparison of the importance of incentives was to derive ratio scores of the best-worst scores. Adamsen et al. (2013) note that by taking the square root after dividing the total best scores by the total worst scores, one can derive ratio scores that assist in the comparison of attribute importance. The square root for all best/worst incentives are then scaled by a factor, such that the most important incentive with the highest square root (B/W) takes the index or interval scale of 100. The authors state that this allows for easy interpretation and comparison across incentives. The resulting coefficients, according to various authors, (Auger et al., 2007; Cohen, 2009; Flynn et al., 2007; Lee et al., 2008 and Marley and Louviere, 2005) measure the choice probability compared to the most important item. A vital component that results from the formulation of the best-worst scores is that of heterogeneity. The following section explains in more detail the issue of heterogeneity from the perspective of a case 1 BWS design.

4.8. BWS Choice Heterogeneity

Adamsen et al. (2013) explain that the first output for case 1 of the best-worst analysis does not reveal any heterogeneity that might be present in the data. Thus, following Adamsen et al. (2013), additional steps such as the calculation of the variance and standard deviations are used as a means of ascertaining whether the choice of attributes (incentives) is consistent amongst all respondents (homogeneity). The standard deviations are calculated based on the individual BWS scores and, as suggested by Mueller and Rungie (2009), incentives with a standard deviation above an absolute one signify the existence of producer heterogeneity.

For a closer examination of heterogeneity among cow-calf producers, a Latent Class cluster analysis (*Latent GOLD*® 5.0) is used to determine whether producers are heterogeneous in their selection of adoption incentives and whether unique classes or segments of producers exist which can be explained by certain farm and farmer characteristics. Vermunt and Magidson (2008) and Haughton et al. (2009) as cited in Umberger et al. (2014) contend that Latent Class cluster analysis is a relatively new clustering technique that assumes individuals belong to one of k Latent Classes, of which the size and number are unknown *a priori*. Umberger et al. (2014) note that the LC is distinct from other approaches such as K-Means cluster analysis, as it involves estimating the probability of class membership using model parameters and observed individual measures. In other words, the method identifies latent classes of respondents within the data.

The authors further state that LC cluster analysis uses the co-variation among individuals' observed preference scores (e.g. BWS scores) as a measure of utility that is used to predict individuals' unique membership in a specific latent class. These observed preferences, are similar among individuals within a class who are assumed to come from the same probability distribution, thus unobserved utility is heterogeneous across classes but homogeneous within a class. LC therefore is dependent on observable attributes captured by the covariates (such as age and gender, for example) and latent heterogeneity that varies with factors that are observable to the researcher (Loureiro and Dominguez Arcos, 2012). The authors note therefore, that it is assumed that individuals are sorted into a set of Q classes or clusters; however, the researcher does not have prior knowledge as to which individuals belong to which class.

Following Loureiro and Dominguez Arcos (2012), the selected choice model is a logit model for a discrete choice among j alternatives (4 for each incentive presented), by each respondent (i) with each of the choice incentives T (13 in this case).

$$\text{Prob\{choice j by individual i in choice situation t|class q\}} \frac{exp(\text{x}'\text{it,j}\beta\text{q})x^2}{\sum_{j=1}^{Ji} \exp\,(x'it,j\beta q)} = \;\; F(i,t,j|q) \tag{4.6}$$

Y_{it} below is used to denote a specific choice made, as the best incentive, so that the model provides:

$$(\text{j}) = \text{Prob}\;(\text{yit} = \text{j}|\text{class} = \text{q}) \tag{4.7}$$

For the given class assignment, the contribution of individual i to the likelihood function would be the joint probability of the sequence y_i = [y_{i1}, y_{i2}, y_{i3}… y_{iT}]:

$$(Pit|q) = \prod_{t=1}^{Ti} (Pit|q) \tag{4.8}$$

A priori the class assignment is unknown. Let H_{iq} denote the prior probability for class q for individual *i*. Similar to Loureiro and Dominguez Arcos (2012), the multinomial logit form is adopted:

$$Hiq = \frac{\exp(Z'i\theta q)}{\sum_{q=1}^{Q} \exp\,(Z'i\theta q)} \tag{4.9}$$

With q (number of classes) = 1. . . Q, where Z denotes a set of observable characteristics which enter the model for class membership. The likelihood for individual *i* is the expectation (over classes) of the class-specific contributions:

$$Pi = \sum_{q=1}^{Q} (HiqPit|q) \tag{4.10}$$

The log likelihood of this classification and selection problem for the sample is therefore presented as:

$$\ln L = \sum_{i=1}^{N} \ln Pi = \sum_{i=1}^{N} \ln \left[\sum_{q=1}^{Q} Hiq \left(\prod_{t=1}^{Ti} Pit|q \right) \right] \tag{4.11}$$

The individual B-W scores for all 13 incentives are used as dependent variables in the Latent Class cluster analysis to explore whether cow-calf producers are heterogeneous in their perceptions of which incentives are most influential in the adoption of the E. coli vaccine. In a similar approach to Umberger et al. (2014), it is anticipated that reactions to incentives described as a series of best-worst choices are likely to be heterogeneous, notwithstanding the different reasons for selecting particular incentives. The heterogeneity that emerges from the survey data can be further evaluated to extract different clusters (classes) of cow-calf producers in order to assess the features and characteristics of each of the identified segments.

A Latent Class cluster analysis is thus used to identify whether cow-calf producers can be segmented based on their choices of the best-worst incentives across the available choice sets. The generated BW scores are used as the indicator variable and social demographic and selected questions from the survey appear as covariates (variables used to describe or predict the indicator variable). Table 4.7 contains the definitions of the socio-demographic characteristics that are included as covariates, with the remainder of the variables applicable to the probit analysis discussed in section 4.9. The covariates include: gender, age, education, livelihood, experience, continuity, and locus of control, which were chosen in line with the literature as possible predictors of classes unknown to the researcher. The LC estimations are performed employing the software Latent Gold 5.0 (Statistical Innovations, 2014).

To summarize, if the most and least important incentives for an E. coli vaccine adoption are found to vary among cow-calf producers, LC analysis makes it possible to characterize or classify these producers into segments based on their latent attitudes toward the incentives. This information can prove useful for stakeholders within the industry and policymakers to better understand the motivations for adopting an E. coli vaccine and the extent to which a latent group of potential “first mover” adopters can be identified and incentivized.

Table 4.7: *Farm and Producer Characteristics and Descriptions*

Characteristic	Variable Description
Gender	Coded as 1 if Male and 0 if otherwise.
Age	Used as a categorical variable in Latent Class analysis, with ‘1’ representing ages 25-34, ‘2’ 35-44, ‘3’ 45-54, ‘4’ 55-64, and ‘5’ > 64. Actual age in years was used for the Probit analysis.
Education	Education level coded as ‘1’, for respondents with an education level at or above the college level and ‘0’ otherwise.
Experience	Years as principal decision maker, used as a categorical variable in LC analysis, with ‘1’ representing less than 4 years, ‘2’ 5-20, ‘3’ 21-35, ‘4’ > 35. Actual number of years (data collected as a range) mid-points for each respondent was used to get an approximation of experience for the Probit analysis.
Continuity	No. of years a producer plans to continue in operation. Data collected as a range, thus the mid-point of the range is used to find an approximation for each respondent.
Awareness	Awareness of E. coli vaccine, coded ‘1’ if the respondent has heard of an E. coli vaccine and ‘0’ otherwise.
Responsibility	Primary responsibility of reducing E. coli incidences is a categorical variable. Dummy variables were created to represent each category coded ‘1’ if cow-calf producers, ‘0’ otherwise. Coded ‘1’ if feedlots, ‘0’ otherwise; coded ‘1’ if packers/processors, ‘0’ otherwise; coded ‘1’ if retailers, ‘0’ otherwise; coded ‘1’ if consumers, ‘0’ otherwise, and coded ‘1’ if regulators and ‘0’ otherwise. (Q.20)
Benefits	Perception of beneficiaries to adoption, coded as ‘1’ if cow-calf producer and ‘0’ otherwise.
Sales/Revenues	Percentage of revenues derived from cow-calf operations. Treated as a categorical variable with ‘1’ representing 0-24%, ‘2’ 25-49%, ‘3’ 50-79%, and ‘4’ 80-100%.
Livelihood	Importance of cow-calf operations to livelihood, coded as ‘1’ if very important and essential and ‘0’ if otherwise.
Retain ownership	Retaining of ownership of cattle/calves, coded ‘1’ if “yes” and ‘0’ if “no”.
Size of operation	Actual Herd size of cattle in operation
Location	Province/territory operation is located. Dummy

	variables were created for each province coded as ‘1’ if AB, ‘0’ otherwise. Coded ‘1’ if SK, ‘0’ otherwise. Coded ‘1’ if MB, ‘0’ otherwise.
Willingness to Adopt	Willingness of cow-calf producer to adopt E. coli vaccine, coded ‘1’ if yes, ‘0’ otherwise (Binary Probit) Coded‘3’ if respondent replies “yes”; coded ‘2’ if respondent replies “don’t know/unsure” and coded ‘1’ if respondent replies “no” (Ordered Probit). (Survey Q. 27)
Locus of control	For LC analysis, an average of internal and external locus questions was utilized and the Likert scale maintained to assess effect of each category. The Probit analysis was similarly done, however, just as a single variable (no categories assessed).
Individual B-W scores	Individual B-W scores calculated for respondent for each incentive.

4.9. Producer Willingness to Adopt

In addition to the Latent Class model, a Binary Probit model is useful to evaluate the determinants of a cow-calf producer’s willingness to adopt a socially beneficial technology such as an E. coli vaccine. As can be seen in the producer survey (Appendix 1), after the best-worst choice tasks section, an anchor question (see question 27) to the best-worst choice tasks was asked to capture the willingness of producers to adopt the E. coli vaccine based on the incentives presented in the prior choice sets. The question was as follows: “would you consider adopting an E. coli vaccine if presented with the right incentives such as some of those appearing above?”

In the Binary Probit model[13], producer willingness to adopt is evaluated using the three categories presented in the survey, with 1 representing the weakest willingness (No); 2 the intermediate willingness (Don’t know/Unsure) and 3 representing the strongest producer willingness to adopt choice (Yes). In order to facilitate the binary approach, the yes responses

[13] It should be noted that in order to explore the effect of different model specifications, an Ordered Probit Model was also estimated , where the dependent variable took the form of 1, 2, 3 to represent the ‘no’, ‘don’t know/unsure’ and ‘yes’ categories. See Appendix 2 for modeling details.

were transformed to 1 with all other responses becoming 0. Following Verbeek (2004), the willingness to adopt function is presented as follows:

$$Y^* = \beta' X + \varepsilon \qquad (4.12)$$

Where y* is a latent unobservable dependent variable, willingness to adopt, coded as 1 for yes and 0 otherwise; β is the vector of estimated parameters, while *x* is the vector of explanatory variables; ε is the error term which is assumed to be normally distributed with $(0, \sigma^2)$ with cumulative distribution denoted by Φ (.). The utility difference between adoption of an E. coli vaccine and non-adoption is expected to depend upon factors including a producer's personal characteristics. Thus, for each producer ***i***, the utility difference between their willingness to adopt and non-willingness to adopt is a function of observed characteristics x_i and other unobserved characteristics captured by ε_i.

4.9.1. *Binary Probit Model*

Following Verbeek (2004), equation (4.13) below shows the probabilities of the 2 available choices being selected.

$$\text{Prob}\ (y = 0 \mid x) = P\ (y^* \leq \alpha_1 \mid x)$$

$$= P\ (x\beta + \varepsilon \leq \alpha_1 \mid x)$$

$$= P\ (\varepsilon \leq \alpha_1 - x\beta \mid x)$$

$$= \Phi\ (\alpha_1 - x\beta)$$

$$\text{Prob}\ (y = 1 \mid x) = 1 - P\ (y^* \leq \alpha_1 \mid x)$$

$$= 1 - \Phi\ (\alpha_1 - x\beta)$$

$$(4.13)$$

The alphas (α) represent cut-off points or thresholds levels. The assumption is that an individual is willing to adopt an E. coli vaccine if the utility difference exceeds a certain threshold level. Consequently we observe $y_i = 1$ (willingness to adopt: yes) if and only if $y_i^* > \alpha_1$ and $y_i^* \leq \alpha 1$ (No) otherwise.

Thus substituting the appropriate form for Φ (.) gives an expression that can be maximized with respect to β using the method of maximum likelihood.

The likelihood function becomes:

$$\text{Ln } L = \sum I_{yi=0} \ln\Phi (\alpha_1 - x\beta) + I_{yi=1} \ln [1- (\Phi (\alpha_1 - x\beta)] \qquad (4.14)$$

Where I_k is an indicator function for willingness to adopt; Φ (.) is defined to be the cumulative distribution and ln being the natural logs.

4.10. Model Specification

The Ordered Probit model that investigates the factors affecting a producer's willingness to adopt the vaccine is as follows (see Table 4.7 for a definition of the variables below):

$$\textit{Willingness to Adopt}_i = \beta 0 + \beta 1\ \textit{Gender}_i + \beta 2\ \textit{Age}_i + \beta 3\ \textit{Education}_i + \beta 3\ \textit{Awareness}_i + \beta 4\ \textit{Responsibility}_i + \beta 5\ \textit{Retain}_i + \beta 6\ \textit{Size}_i + \beta 7\ \textit{Livelihood}_i + \beta 8\ \textit{Experience}_i + \beta 9\ \textit{Location}_i + \beta 10\ \textit{Continuity}_i + \beta 11\ \textit{Benefits}_i + \beta 12\ \textit{Locus}_i + \beta 13\ \textit{Individual Best-Worst Scores}_i + \varepsilon_i \qquad (4.15)$$

Where:

i: individual;

ε_i: is assumed to be a random error with a zero mean and finite variance.

Equation (4.15) with ε_i following a normal distribution is modeled as both a Binary and Ordered Probit model and is estimated by a maximum likelihood technique. The explanatory variables are included on the basis that they are observable and are deemed *a priori* to inform a producer's willingness to adopt an E. coli vaccine. In addition to these variables, aggregated BWS scores are included in order to ascertain the effect of each of the incentives presented on producer willingness to adopt.

This chapter has outlined the methods that are used to carry out and analyze the internet based survey of cow-calf producers' willingness to adopt an E. coli vaccine. Particular emphasis was placed on the BWS choice tasks, the main empirical section of this thesis. The BWS was utilized to give a clear indication of which incentives are considered to be important to producers in improving their willingness to adopt the E. coli vaccine. Case 1 of the BWS in this instance provides policymakers, supply chain participants and other stakeholders with aggregate level information on the incentives that are most acceptable to cow-calf producers and alternatives that would likely be rejected by the producers. Survey questions not discussed in this methodological section are used for descriptive data analysis to explore further the research questions highlighted in chapter 1 of this thesis.

Concurrently, this chapter also sought to explain how, using Latent Class cluster analysis, Chapter 5 identifies segments/classes of cow-calf producers with heterogeneous preferences towards the adoption incentives. Furthermore, a Binary/Ordered Probit model identifies the determinants/factors that are most likely to affect a producer's willingness to adopt an E. coli vaccine. Results from these analyses are presented in the data analysis and empirical results chapter (5) which follows.

CHAPTER 5

5. RESULTS OF THE CANADIAN COW-CALF PRODUCER SURVEY

5.1. Introduction

This chapter reports results of the online Canadian cow-calf producer survey administered in July 2014. Ipsos Agriculture and Animal Health were commissioned to administer the survey. Cow-calf producers were recruited via e-mail from an on-line panel of Canadian cattle producers managed by Ipsos Agriculture and Animal Health. Screening questions were used to select producers with varying sizes of operation. Confirmation of whether the intended participant had either overall or joint responsibility for animal health management practices in their operations was used as a further screening question. In addition, quotas were set for the number of responses from each province (AB, SK, and MB) in order to match the share of cow-calf production in each province. Respondents were assigned unique identification codes by Ipsos to guarantee anonymity and limit the potential for response duplication. After ascertaining the validity of responses, all respondents were retained to make up the final dataset. A token of CDN $20 was provided to participants who completed the study.

The results are organized as follows: first, the socio-demographic characteristics of the sampled cow-calf producers are presented in section 5.2. Second, descriptive statistics are provided on respondents' awareness of the E. coli pathogen and E. coli vaccine; on the impact of E.coli outbreaks on producer operations; the sources of information for E. coli used by producers, perceptions on who bears the primary responsibility for E. coli reduction within the supply chain, and perceptions regarding who are the major beneficiaries from vaccine adoption are presented in section 5.3. Third, assessment of current management intervention controls/practices utilized by producers and the confirmation of whether there is currently an existing vaccination routine are discussed in sections 5.4 and 5.5 respectively. Fourth, the barriers to adoption of an E. coli vaccine are identified in section 5.6; the results from the BWS analysis on the relative influence of the 13 incentives are then described in section 5.7 and 5.8 to show which incentives have a greater potential to encourage adoption. Lastly, results from the Latent Class analysis and Binary Probit model are discussed in sections 5.9, through 5.10, and 5.11 respectively.

5.2. Socio-demographic Characteristics of Cow-calf Producers

A final total sample size of 203 was yielded from the survey process.[14] The majority of the sample population was male (79.3%) with female cow-calf producers accounting for 20.7% of the sample (Table 5.1). The average age of respondents was 54, which is identical to the average age of Canadian farm operators according to the Statistics Canada Census of Agriculture (2011) (see Table 5.1). The respondents' age ranged from 77 to 29. In terms of the total percentage of sales/revenues derived from cow-calf operations, on average 42.1% of gross farm revenues came from cow-calf operations.

The survey sample by province is reasonably comparable with the aforementioned Canadian industry statistics, with 46.8% of the respondents located in Alberta, 35.5% in Saskatchewan and 17.7% in Manitoba. The size of operation (herd size) had a mean of 210, which is greater than that of the Canadian population at 63. The maximum herd size was 11000 and minimum 2. As noted before, varying sizes of operations were targeted using quotas for different operation sizes in order to capture a wide array of cow-calf producers (see Appendix 3 for herd size distribution).

[14] The final sample size included only fully completed surveys responses. Respondents could opt out or quit the survey at any time with incomplete surveys not included in the final sample size. Information on the number of incomplete surveys is not available.

Table 5.1: Selection of Socio-demographic Characteristics of Cow-calf Producers

Socio-demographic characteristics of cow-calf producers	Min	Max	Mean/ Percentage	Comparative Canadian statistics	Std. Deviation
Gender					
Male			79.3		
Female			20.7		
Age	77	29	54	54+	9.954
Percentage of total 2013 gross farm sales/revenues derived from cow-calf operations	1	100	42.12		29.147
Province					
AB			46.8	40.7	
SK			35.5	29.8	
MB			17.7	11.6	
Size of Operation (herd size)	2	11000	210	63+	834.77

+Source: Statistics Canada, Census of Agriculture, 2011.

The cow-calf producers in the sample population were fairly well educated, with 35.5% of the respondents having attended trade school/college and 34.5% of respondents holding secondary/high school certification. Furthermore, 28.1% of the respondents had a university education with only 2% holding only a primary/elementary education. In comparison to the general population the sample population was highly educated, perhaps suggesting that online surveys, in this case the online panel used by Ipsos, tend to be biased towards more educated respondents.

With respect to years of experience in the industry, 35.5% of the sample population had above 35 years of experience as principal decision makers, with 33.5% of respondents falling in the 21-35 years category, and 27.1% possessing between 5-20 years as principal decision makers. Producers were asked how long they plan to be in the cow-calf business on the premise that this question has the potential to shed light on adoption decisions since it was assumed that the length of time that producers plan on continuing in the cow-calf business can potentially influence the introduction of food safety technologies such as an E. coli vaccine. The survey revealed that

31.5% of respondents planned on continuing as cow-calf producers for between 10-25 years, with 29.6% specifying 6-10 years, 26.1% stating 1-5 years, and 8.9% indicating more than 25 years.

The inclusion of the question on the importance of cow-calf operations to a producer's livelihood sought to assess the notion that producers who depend on their operations as the primary means of their livelihood may be more likely to be willing to invest in technologies to protect their investment. The majority of respondents indicated that their cow-calf operations were important to their livelihoods, although to different degrees. Specifically, 35.5% of respondents suggested that their cow-calf operations was fairly important to their livelihood, with 35% indicating it was very important and 21.7% suggesting it was essential.

5.3. ECONOMICS OF INCENTIVES

5.3.1. Awareness of E. coli O157:H7, related outbreaks and the E. coli Vaccine

The awareness questions included in the Canadian cow-calf producer survey were included to find out the knowledge that producers possess regarding the E. coli pathogen and the recent E. coli outbreaks that have affected the beef and cattle industry. Moreover, producers' knowledge and perception of the E. coli vaccine technology, which has been available in the market since 2008, were also examined. This section is particularly important for the simple reason that knowledge, understanding and awareness of E. coli and its related issues is likely to be important to producers' willingness to adopt the technology.

Cow-calf producers were asked about their familiarity with the E. coli *O157:H7* pathogen (see question 6). 59.1% of the respondents indicated that they were somewhat familiar with E. coli while 17.2% were very familiar, bringing familiarity to a total of 76.3% (Figure 5.1). On the other hand, 14.8% and 8.9% of cow-calf producers stated that they were somewhat unfamiliar and very unfamiliar with the pathogen respectively. These results are consistent with the survey of Canadian cattle producers conducted by Strategic Research Associates on behalf of Bioniche

Life Sciences in 2010, where the authors reported 75% of Canadian cattle producers were familiar with the E. coli pathogen.

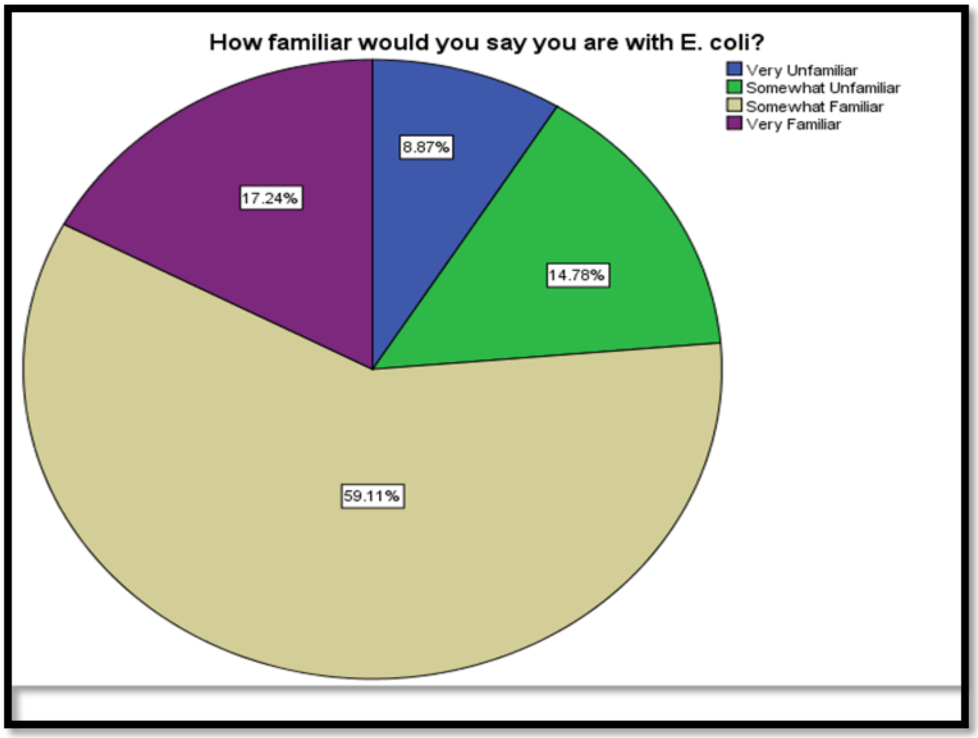

Figure 5. 1: Awareness of E. coli *O157:H7*

In relation to familiarity with E. coli outbreaks that have taken place in Canada since 2000 (see question 7), the majority of the respondents stated that they were somewhat familiar 66.5% and 9.4% very familiar with such E. coli incidences (Figure 5.2). Only 18.2% and 5.9% of cow-calf producers were somewhat unfamiliar and very unfamiliar with episodes of E. coli outbreaks. Producers were prompted further with an open ended question to list any cases of E. coli outbreaks they were aware of since 2000. Frequently mentioned E. coli incidences included the Walkerton, Ontario E. coli case and the XL Foods Inc. E. coli outbreak in Brooks, Alberta (2012), which resulted in the largest beef recall in Canadian history. Also mentioned, was the (2013) E. coli incident that took place in British Columbia as a result of cheese being manufactured using unpasteurized milk.

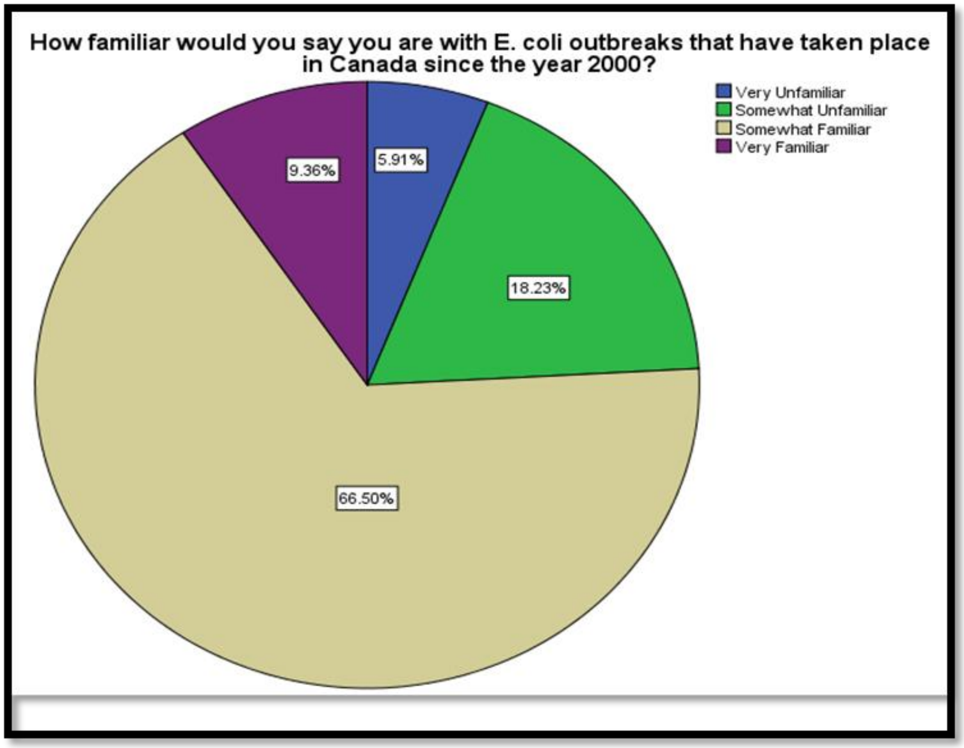

Figure 5. 2: E. coli Outbreaks Awareness

After producers were assessed on the E. coli pathogen and related incidences, a question was posed on whether they had ever heard of an E. coli vaccine such as the Canadian made brand Econiche. About 46.3% of the respondents indicated that they had heard of the vaccine but had never used it, 4.9% specified that they have used the vaccine and are currently still using it (Figure 5.3). Whereas 41.9% stated that they have never heard of the vaccine, while 6.9% indicated that they have heard about and used the vaccine before, but are currently not using it. These results suggest that more would need to be done in sensitizing Canadian cow-calf producers to the food safety technologies that are available for them to utilize in their operations as in this case of an E. coli vaccine. This can be done in tandem with cow-calf producers' major information sources on animal health as presented in the information sources subsection.

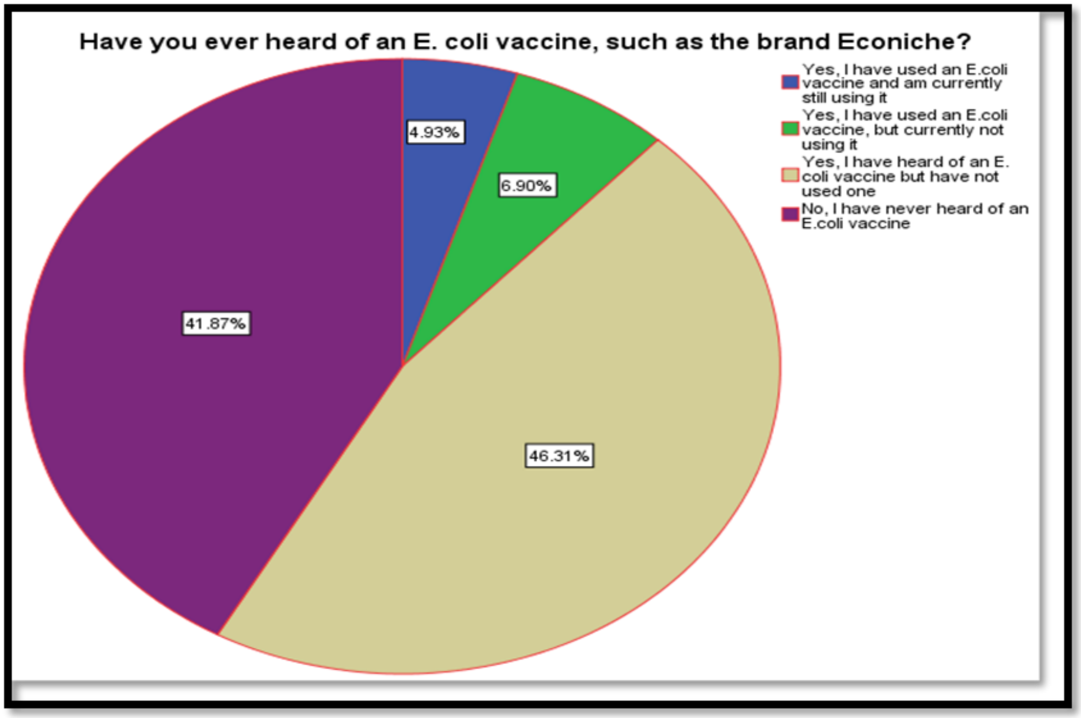

Figure 5. 3: E. coli Vaccine Awareness

For those respondents who stated that they had heard of and were currently using the E. coli vaccine or had used it before, a follow-up question on the motivation behind usage was posed. About 6.4% of these producers, 24 in total, suggested that they used or are using the vaccine based on the recommendation of their veterinarian, while 3.4% used it on a trial basis. In addition, the awareness of the cost of the E. coli vaccine was sought from producers that had heard of the E. coli vaccine, 118 in total, to get a sense of a producer's knowledge of the technology. The sizeable number of the producers, 47.3%, specified that they were not aware of the cost of the vaccine, while 10.8% indicated they were indeed aware of the cost. Finally, a question concerning producer confidence in the level of immunization that the E. coli vaccine provides was asked. From this pool of 118, 31.5% indicated that they were not confident about the level of immunization provided, while 26.6% of the sub-sample responded in the affirmative, with 41.9% representing those producers who had not heard of the E. coli vaccine before.

The awareness questions were helpful in establishing a more informed picture on the current status of adoption of the E. coli vaccine. This was done through the assessment of producer knowledge and understanding on the current and technical issues involving E. coli *O157:H7*, its related outbreaks and a potential solution of an E. coli vaccine. This set the stage for finding out where producers obtain their knowledge of the E. coli pathogen leading to the examination of producer information sources as discussed below.

5.3.2. Information sources on E. coli O157:H7

Respondents were asked about their primary sources of information regarding E. coli (see question 10). In Figure 5.4, it is evident that the most popular primary source amongst producers was producer associations (federal or provincial) with 36.9%. The second most popular primary source was a producer's veterinarian, garnering 29.1% of responses. About 11.3% of respondents however, indicated that they currently did not have any sources of information regarding E. coli matters, whereas 10.3% stated they received their information from government information agencies/services such as provincial ministries. On being asked which primary source of information they consult first, 44.4% selected their veterinarian followed by government information agencies at 17.8%; internet searches 16.7%. Furthermore, producer associations, other cow-calf producers and consultants were consulted first by 12.8%, 7.2% and 1.1% respectively.

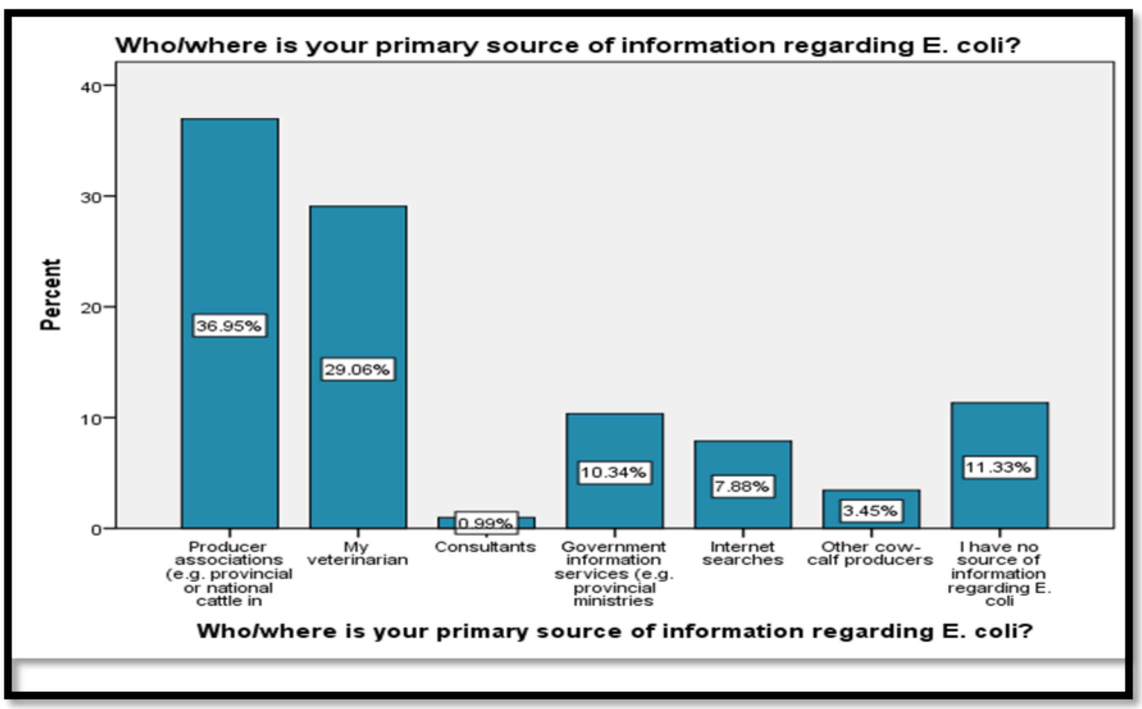

Figure 5. 4: Primary Sources of Information on E. coli

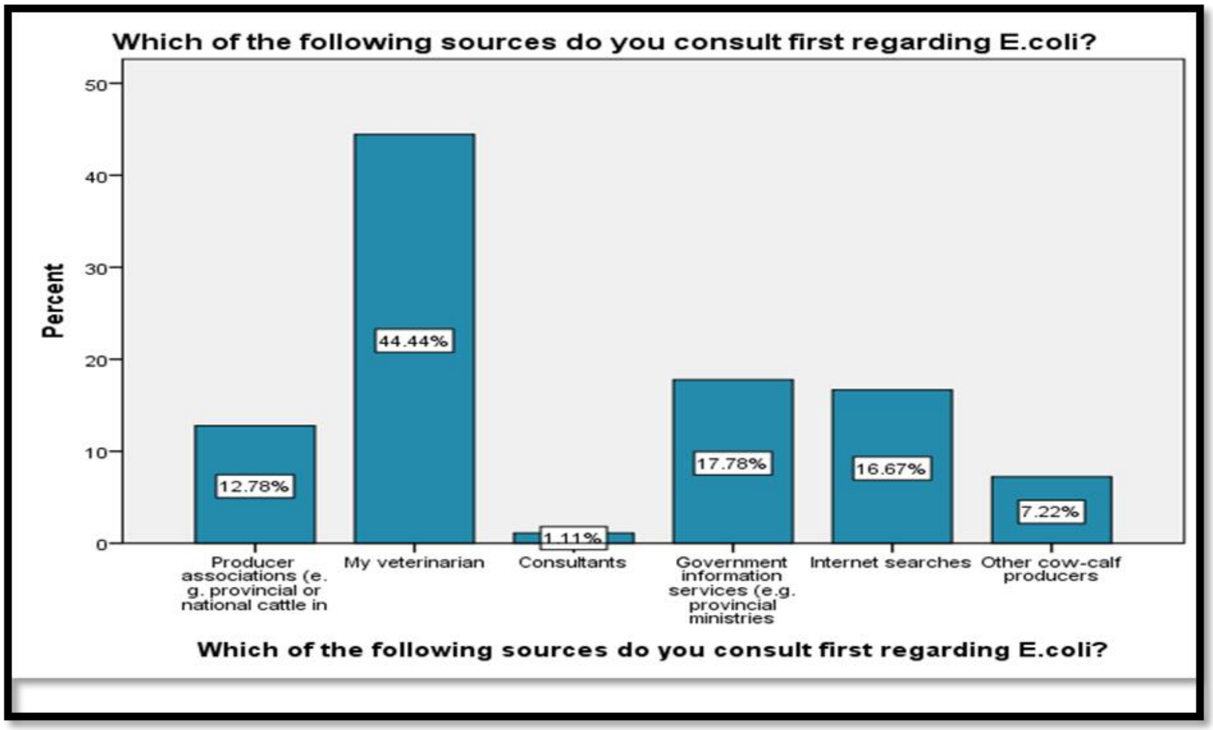

Figure 5. 5: Priority Consultation of Primary Information Sources

These results show that veterinarians are typically the first contact regarding technical issues on animal health to many Canadian cow-calf producers. Other cow-calf producers were not typically the first option as a primary source of information, and this result is confirmed by the relatively low influence of the incentive "my neighbours are adopting the E. coli vaccine" (see BWS analysis in section 5.7).

5.3.3. Responsibility for E. coli reduction within the supply chain

Cow-calf producers were asked who they think has the primary responsibility for reducing the risk of E. coli problems within the beef supply chain (see question 20 of survey). The majority of the respondents, 56.2%, indicated that processors/packers have the primary responsibility for reducing the risk of E. coli problems. Meanwhile, 15.3% of respondents indicated that the primary responsibility lay with cow-calf producers, 15.3% feedlots, 7.8% consumers and 5.4% regulators such as the CFIA. A follow-up question on secondary responsibility yielded quite similar results, albeit a rescaling in the weights, with 25.1% of producers believing that the secondary responsibility should lie with processors/packers and 23.6% suggesting feedlots, 16.7% suggesting regulators, 9.8% consumers and 11.3% cow-calf producers. Cow-calf producers' perception of which supply chain participant should bear primary responsibility is closely related to the perception of how the benefits of adoption are spread. The next section explores this link.

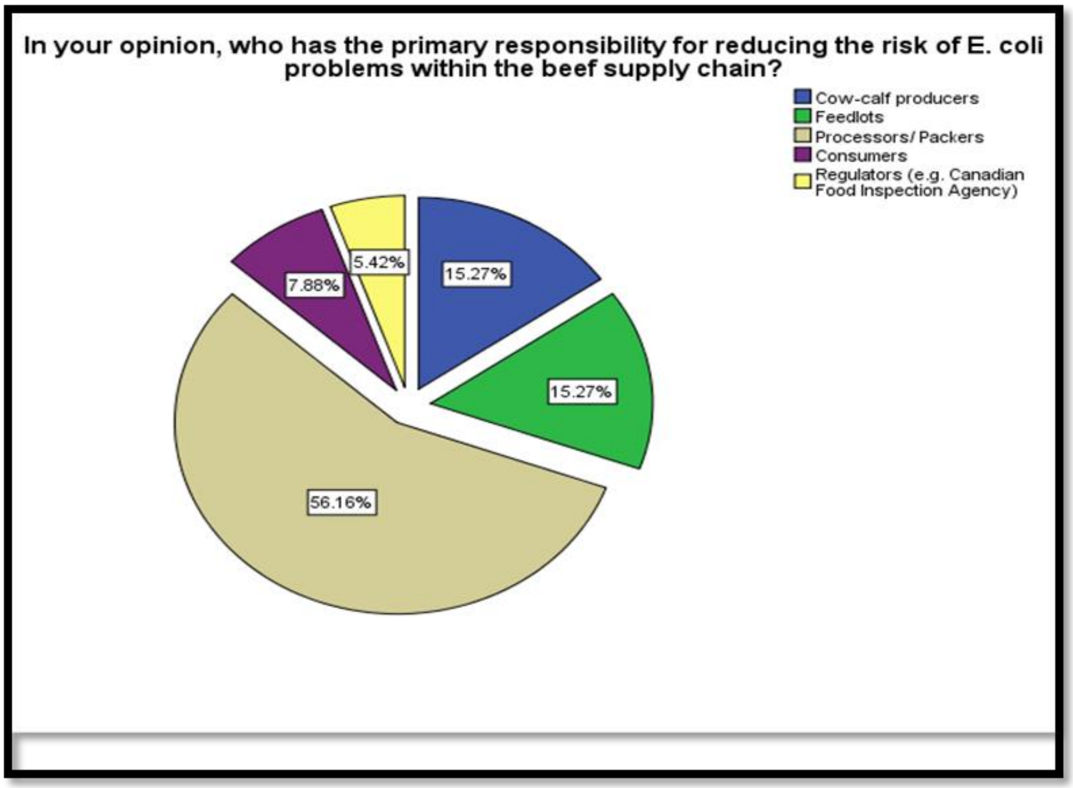

Figure 5. 6: Primary Responsibility of E. coli Reduction

5.3.4. Benefits of E. coli vaccine adoption

As can be seen in Figure 5.6, a significant proportion of respondents, 40.9%, believed consumers to be the main beneficiaries from the use of E. coli vaccines. This is followed by processors/packers at 26.1%, then cow-calf producers at 20.7%. As discussed in the theoretical considerations chapter, the notion of positive externalities/public good dynamics comes into play in this case. This result confirms earlier assertions about the perceived flow of benefits going elsewhere within the supply chain other than to the adopters, which perhaps explains the current low level of adoption amongst Canadian cow-calf producers. Feedlots on the other hand were expected to be the primary beneficiaries by 7.4% of respondents; retailers by 3.9% and municipal water security agencies by only 1% of respondents. In relation to the municipal water security agencies result, this option was included in the question to reflect potential environmental benefits given the potential for E. coli to affect ground water systems through farm run-offs. This result is surprisingly low and probably understates the extent to which protection of drinking water supplies is a potential benefit of this type of intervention in the Prairie provinces.

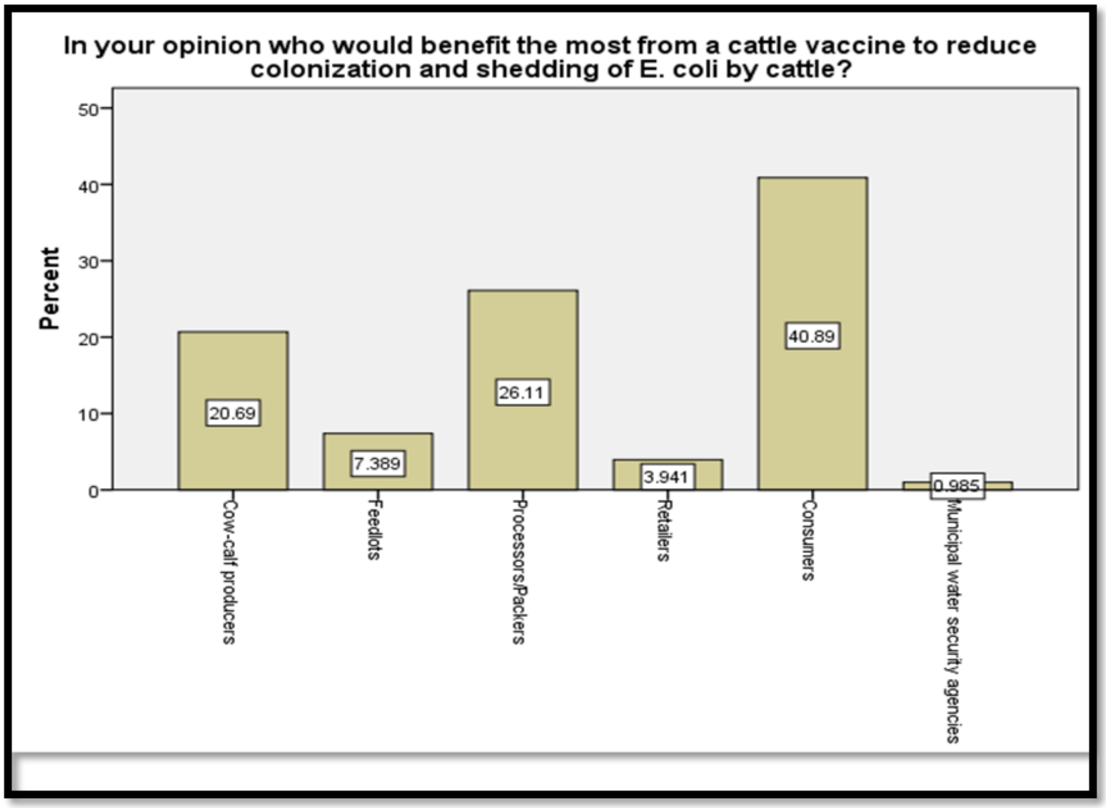

Figure 5. 7: Perceived Top Beneficiaries from Cattle Vaccine Adoption

Following from the results presented above, it is evident that the majority of surveyed Canadian cow-calf producers currently do not utilize an E.coli vaccine as a means of combating potential E. coli hazards and believe that the primary beneficiaries of the vaccine would be consumers and processors. Current interventions and management controls/practices were assessed to ascertain what measures cow-calf producers have in place within their operations to mitigate against E. coli incidences.

5.4. Current use of management controls which mitigate E. coli incidences

This particular section of the survey (see question 24: management practices currently in use to reduce E. coli incidences) was important given that at present market penetration of the E. coli vaccine is low, as outlined in Chapter 1 of this thesis. In this light it is useful to know what current practices Canadian cow-calf producers have in place to control against the presence and spread of E. coli in their operations. This low market penetration of the E. coli vaccine is confirmed by producer responses when asked whether they vaccinated their cattle as a form of management control for E. coli colonization and shedding, with 18.2% answering in the affirmative as shown in Figure 5.8. For purposes of analysis, the interventions are grouped into common categories such as physical barriers, treatments and use of an environmental farm plan.

5.4.1. Physical Barriers

A number of interventions or management practices in question 24 require physical alteration or additions to the farming environment as a means of reducing the risk of the spread of the E. coli pathogen. With regard to the management practice of removing of farm animals from the proximity of private water supplies, Figure 5.8 shows that 63.1% of cow-calf producers indicated that they follow this practice. Further, 28.1% of respondents fenced off streams to prevent access by their livestock. The use of fencing to keep livestock/pets from ready to eat crop areas was fairly common, with a majority of producers 62.1% stating that they actively keep livestock and pets out of these areas. The use of vegetative buffer strips to stop run-off and control contamination of ready to eat crops was utilized by 43.8% of cow-calf producers, while the prohibition of recreational activities such as walking and camping was used by 38.4% of respondents. The prevention of contact with neighbouring cows via double fencing was used by 27.6% of producers. In relation to the prevention of ground water system contamination from farm run-off, 73.9% of producers claim that they utilize this particular management control. This result is in contrast with the very low level of concern for E. coli contamination of water captured by producer’s perception of benefits flowing to municipal water agencies.

5.4.2. Treatment

The use of probiotics as a measure to reduce E. coli shedding rates was put into practice by only 13.8% of producers (Figure 5.8). The treatment of water supplies through the process of ozonation, chlorination or ultra-violet treatment was utilized as a measure by 24.6%[15] of respondents. When respondents were asked about not mixing groups of young stock once formed as a measure of curbing the transmission of the E. coli pathogen, 40.4% of the respondents indicated that they put this control into practice. The monitoring of private water supplies to identify those with higher indicator or counts, or those in high risk areas was put to use by 36.9% of respondents.

5.4.3. Environmental Farm Plan

The results concerning the use of an Environmental Farm Plan (EFP) suggest that a majority of respondents are more conscious about the impact their operations can have on the environment. About 63.5% of producers indicated that they currently have an environmental plan in place for their operations. Statistics Canada (2013) note that the use of environmental farm plans in Western Canada is a relatively new phenomenon, unlike provinces such as Quebec and the Atlantic region where the number of farms with a formal EFP exceed the number of farms without a formal EFP. Statistics Canada (2013) further state that in Quebec's case, approximately seven out of ten farms had a formal EFP possibly due to provincial legislation that targets nutrient and manure management issues. In contrast they noted that fewer than three out of ten farms in Manitoba, Saskatchewan, Alberta and British Columbia had a formal EFP program. It should be noted that in order for a farmer to be eligible to receive best management practices (BMPs) cost share payments, a completed EFP is required.

Such a result can be dissected in two ways. In spite of lack of provincial legislation being in place to target nutrient and manure management issues as in the Quebec case, the majority of respondents claim to have adopted a beneficial management practice that can help mitigate or

[15] This figure is surprisingly high, possibly suggesting that these survey questions are privy to agreement or social desirability bias and therefore should be interpreted with caution.

eliminate risks of pathogens such as the E. coli *O157:H7*. This is an encouraging sign toward the future outlook of mitigation strategies, despite the low adoption of technologies such as the E. coli vaccine. On the other hand, for those producers that indicated that they currently did not have an environmental farm plan in place, this is consistent with the use of an environmental farm plan in western Canada as being solely voluntary. This result, however, differs from the Statistics Canada (2013) finding. Given the fact that producers were recruited through Ipsos Reid's Animal health database there is the possibility that the respondents were more likely to be engaged in these types of pro-active management practices, and/or the responses may suffer somewhat from social desirability bias, and thus this result should be interpreted cautiously.

The more popular interventions currently being utilized by Canadian cow-calf producers based on the results above are related to physical barriers being strategically implemented to limit the E. coli pathogen. The use of treatments or preventative methods such as use of probiotics and vaccination of cattle using an E. coli vaccine are not on producers' high priority usage list. The existence of a current vaccination routine may influence incentives to adopt an additional (E. coli) vaccine if it affects the scale of change necessary. This section now follows.

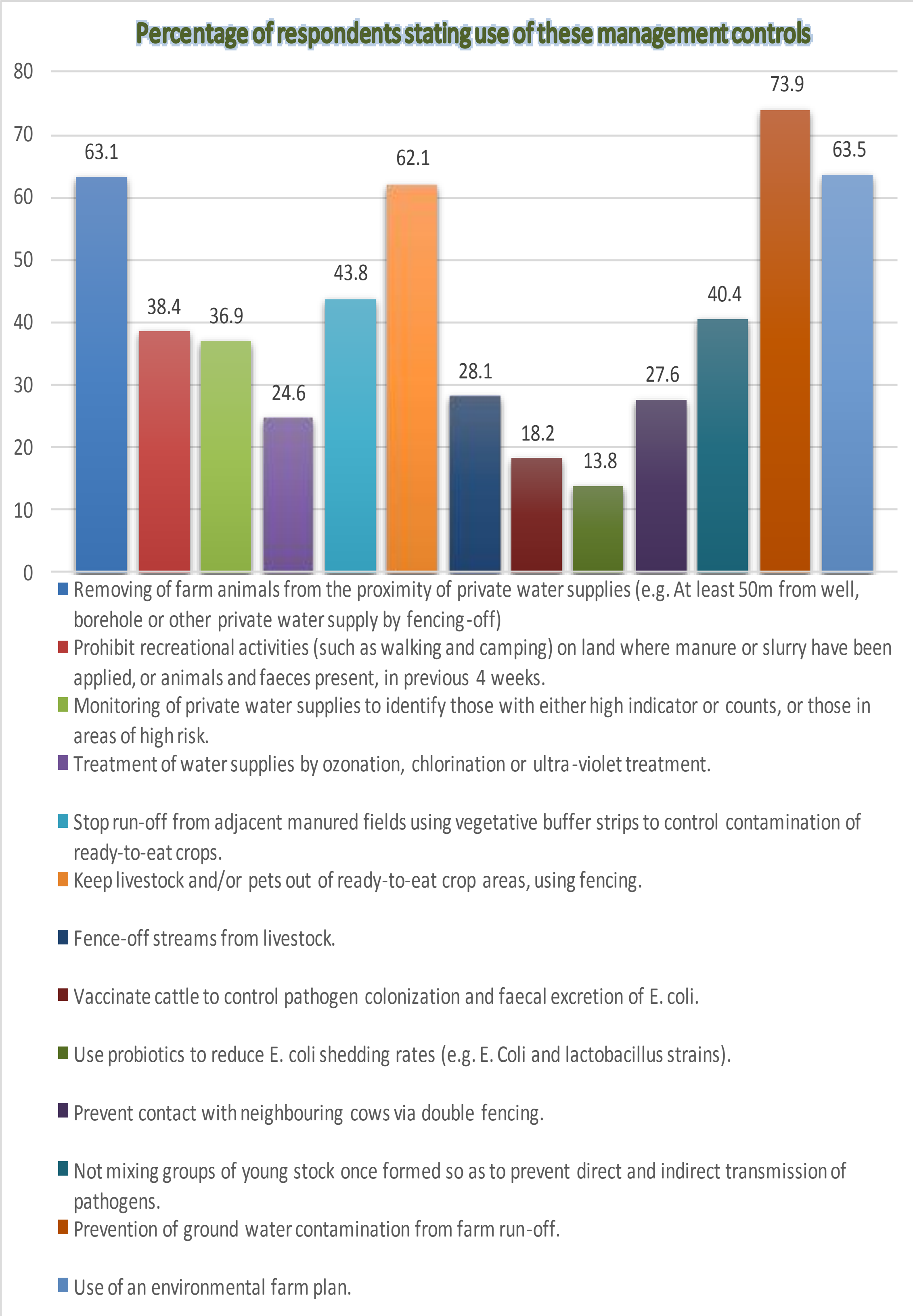

Figure 5. 8: Percentage of Respondents Stating Use of E. coli Management Controls

Overall, from the listed management controls presented to respondents above, four of these controls qualify for BMPs. These include: removing of farm animals from the proximity of private water supplies, stopping run-off from adjacent manured fields using vegetative buffer strips to control contamination of ready-to-eat crops, fencing-off streams from livestock, and lastly, prevention of ground water contamination from farm run-off. Literature suggests that on average, 52.5% of farmers are willing to use these BMPs in comparison to 32% that are willing to use the other listed management controls. A case can thus be made for the inclusion of the management control of vaccinating cattle to mitigate against pathogen colonization and faecal excretion of E. coli as part of BMPs in order to encourage wider adoption of the E.coli vaccine. However, literature on BMPs suggests that if these controls do not fit in well with the current farming routine/protocol, farmers are not likely to adopt them despite incentive payments associated with BMPs.

5.5. Existence of a vaccination routine/protocol

One of the inhibitors to the adoption of the E. coli vaccine is the expected impact it might have on the cost of production. Thus the extent to which cow-calf producers can include an E. coli vaccine in their existing vaccination routine is relevant since this may be less costly than if the E. coli vaccine is administered as a standalone solution. Respondents were asked a series of questions in the survey including whether they currently vaccinate their calves against any form of diseases (see question 12). An overwhelming amount of producers, 86.7%, responded in the affirmative, and only 13.3% indicated that they currently did not vaccinate their calves.

A follow-up question was posed asking how often most of the calves are vaccinated (question 13). Cow-calf producer responses in this case were consistent with *a priori* expectations, with 48.8% stating that they vaccinated twice a year while 38.9% vaccinated once a year. Only 3% of producers indicated they vaccinated their calves/cattle more than twice a year. Bioniche Life Sciences Inc. recommends that calves be vaccinated twice a year using the E. coli vaccine.

Respondents were then asked who typically vaccinated their cattle (see question 14) and the majority of producers, 72.9%, specified that they typically do the vaccinations themselves. About 5.4% of respondents indicated that they utilize their veterinarians, while 4.4% stated they do it themselves but with the supervision of their veterinarians and 3.9% indicated an employee carries out the vaccination process. The Econiche vaccine protocol is such that Bioniche Life Sciences Inc. strongly recommends veterinarian support given that the vaccine is only made available through a veterinary specialist, who either administers the vaccine or supervises the process. This result thus suggests that the need to use a veterinarian could deter adoption due to added costs. On the other hand, this can be seen as a feasible way to verify the use of an E. coli vaccine through a third party which may be useful in the emergence of specialized vaccinated cattle supply chains. In relation to how much cow-calf producers spend in total on vaccines per year for each calf, 30% of respondents indicated that they spent on average about \$5-\$6.99, while 28% and 26.6% of producers stated that they spent more than \$7 and between \$1-\$4.99, respectively, per calf.

Having established the existence of an ongoing vaccination protocol that has potential in affecting the cost of adoption, the survey further sought to identify other barriers to adoption faced by Canadian cow-calf producers. The following section provides details of these barriers.

5.6. Barriers to adoption of the E. coli Vaccine

This section presents a set of potential issues that could have deterred producers from adopting the vaccine. Respondents were asked to indicate with a 'yes' or a 'no' whether these issues qualified as barriers (see question 28). To recall, these barriers were identified through the review of literature and pre-test interviews conducted in the survey design. Based on the results, the underlying theme resonating from the data is that Canadian cow-calf producers are risk seeking when it comes to the investment in technologies such as the E. coli vaccine.

The uncertainty of whether the adoption of the E. coli vaccine would meet the needs of the buyer(s) of my cattle was considered to be a major barrier. The majority of producers, 71.4% indicated that such uncertainty was enough to deter them from using the E. coli vaccine. Uncertainty about whether adoption of the E. coli vaccine will improve food safety was also found to be a significant barrier, with 68.5% of producers specifying that this particular issue served as a deterrent to adoption of the vaccine technology. Another issue involving uncertainty was the issue of pay-off/premiums being available as a result of adoption of the E. coli vaccine. The majority of producers, 76.8% stated that this issue deters them from adopting (Figure 5.9).

Other perceived barriers, such as the cost of production, were expected to be of major concern for Canadian cow-calf producers in their quest to remain competitive and profitable in their operations. Thus there was an *a priori* expectation that costs would be an important barrier to adoption. Respondents were divided with respect to incurring an additional cost as a result of adoption, with approximately half of the producers, 49.3% indicating this as a deterrent to adoption (Figure 5.9). Other issues presented as potential deterrents to adoption were not perceived to be significant barriers. These include: not enough of my neighbours adopting, which is fairly consistently sidelined as a non-influential factor in producer decisions throughout the results (see BWS analysis). Furthermore, food safety issues not being sufficiently important to warrant investment on E. coli vaccines were perceived as a barrier by only 24.1% of respondents.

Based on the discussion above, the issues that would deter cow-calf producers from adopting an E. coli vaccine appear to be more related to uncertainty as to whether the vaccine would address food safety concerns, meet buyer needs, and generate the necessary premiums to allow recoupment of investment in vaccine technology. This suggests that these barriers can be addressed using incentives that lessen the uncertainty surrounding the adoption of the E. coli vaccine. The Best-Worst Scaling (BWS) analysis is used to assess the influence of these incentives on producer adoption decisions.

Having presented and discussed the barriers to adoption of an E. coli vaccine, 13 incentives which can potentially influence the adoption decision were identified from the literature and pre-survey interviews. The analysis of these incentives through BWS is presented in the next section.

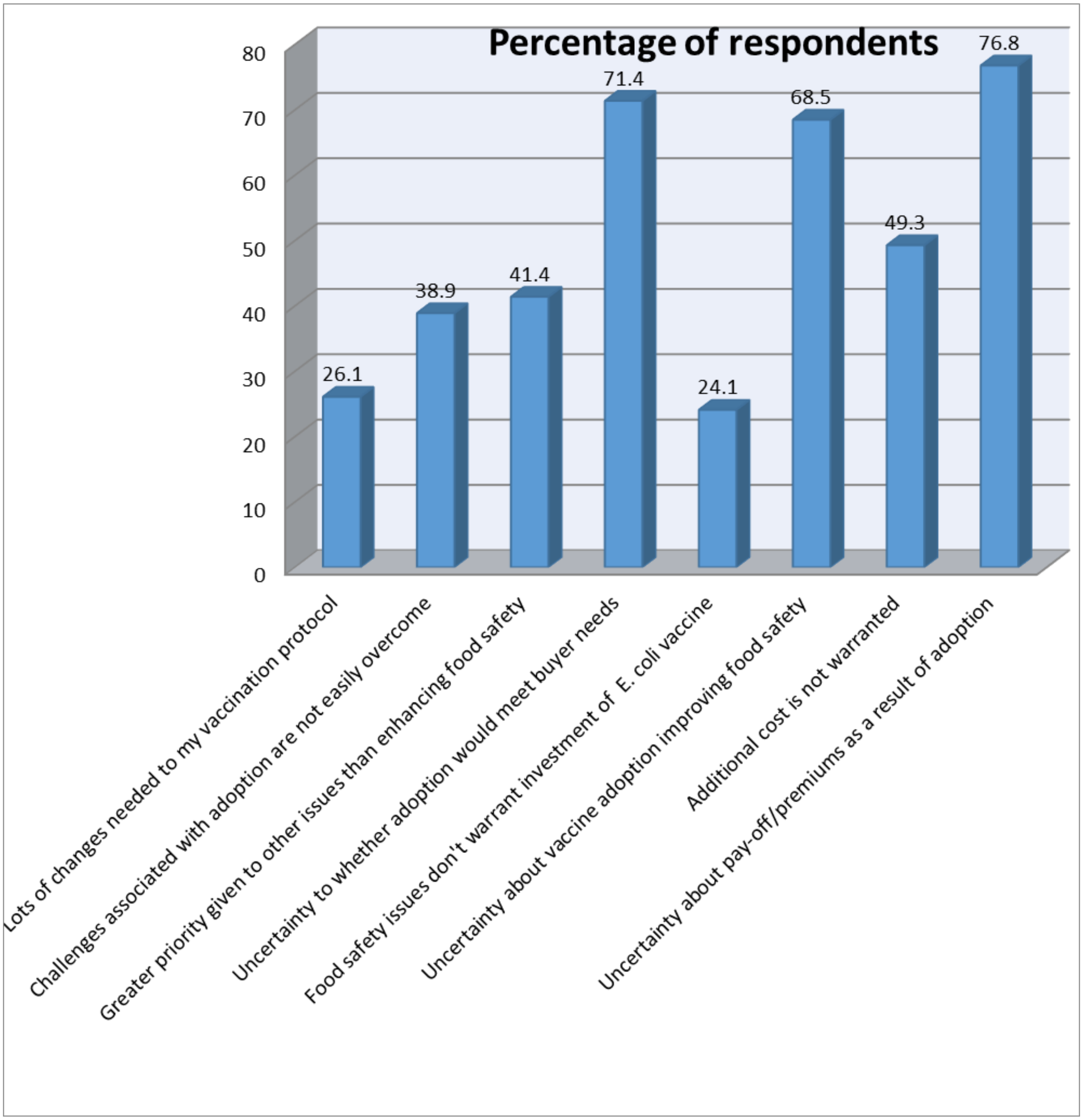

Figure 5. 9: Barriers to Adoption

5.7. BWS Analysis

The main objective of this analysis is to examine the relative strengths of various incentives to adopt the E. coli vaccine technology. As discussed in the introductory chapter, the current under-utilization of the vaccine, despite its availability since 2008, is likely due to the positive spill-over effects accruing to other stakeholders within the supply chain other than the technology adopters.

Following the formula specified in the analytical method section 4.7.2 of the methodological chapter, a standard score was computed. This initial simplified rank ordering process creates individual-level scales for each attribute that are easily comparable across the entire sample (Coltman et al., 2011). These attribute scales are computed from the individual B-W scores of each respondent, aggregated across the sample for each identified incentive.

In order to calculate the ranking of the various incentives used in the sample data, a first calculation of the results is computed using the standard BWS summary statistics. Table 5.2 shows the importance (influence) and ranking of each attribute or incentive presented in the BWS choice tasks, ranked in terms of most to least important. The maximum difference is measured as the difference between total best scores and total worst scores marked for each incentive presented in the survey (aggregated B-W score) (see the explanation in section 4.7.2).

Based on the aggregated B-W across respondents and standard scores, the data indicated that the incentives “premiums for E. coli vaccinated cattle are available through various programs (e.g. branded beef program) within the supply chain” (selected 307 times with a 0.378 standard score) and “subsidy to compensate the costs of my adoption of the vaccine is available through a government funded vaccination program” (selected 280 times and 0.345 standard score) are perceived as the most preferred and second most respectively in incentivizing producers to adopt the E. coli vaccine across the entire sample. In addition, supply chain co-ordination in the form of “my buyer requiring use of an E. coli vaccine as part of production protocol as a condition for accepting my calves/cattle” was the third most influential incentive (selected 260 times with a score of 0.320). This was followed by the “attraction of new sets of buyers” as the fourth most influential incentive (selected 110 times with a score of 0.135) as a result of vaccinating cattle with the E. coli vaccine. Recommendation from my veterinarian to use the E. coli vaccine in my operations was the fifth most influential incentive (selected 88 times with a score of 0.108), while "I can include an E. coli vaccination in my existing vaccination routine" was selected as the sixth most important incentive (selected 86 times with a score of 0.106) (Table 5.2).

These results reveal that the top five incentives are dominated by market/supply chain oriented incentives (availability of premiums through branded beef programs, attraction of new sets of buyers and buyer requiring use of vaccine as part of production protocol). This suggests the possibility of closer supply chain co-ordination, such as branded beef programs, as a potential means to strengthen the current low adoption rates.

On the other hand, the least preferred or influential incentive for the entire sample is "government recommending the use of the E. coli vaccine" which garnered a total worst count of 482 responses, with an aggregated B-W score and standard score of (-427 and -0.526). The second least influential incentive is "my neighbours adopting the E. coli vaccine" with an aggregated B-W and standard score of (-297 and -0.366).

In the theoretical considerations chapter, the framework of the Tragedy of Anti-Commons was discussed. This particular theory explored the notion of the majority of other cow-calf producers' adoption influencing producers to adopt the E. coli vaccine technology. This notion, however did not hold as indicated by the results. Therefore, if cow-calf producers within close proximity are adopting, other producers are not more likely to adopt for this reason. The third least influential incentive in Table 5.2 is "feedlots providing an assurance that they will give my cattle a booster of the E. coli vaccine to maintain the immunity of my cattle" (-203 and -0.250). The idea behind this incentive was to preserve or protect the investment that a cow-calf producer makes if they adopted the E. coli vaccine, given the fact that feedlots may also deal with non-vaccinated cattle. The implications of these results are such that these incentives are unlikely to change the behaviour of cow-calf producers.

Table 5.2: Best-Worst Scaling Summary Statistics

Incentive	Total Best	Total Worst	Aggregated B-W Score	Average B -W Score (Standard Score)	Ranking based on Standard Score
Premiums available through beef branded programs	392	85	307	0.378	1
Subsidy to compensate costs of adoption is available	357	77	280	0.345	2
My buyer requiring use of vaccine as part of production protocol	327	67	260	0.320	3
Attraction of new buyers for vaccinated cattle	249	139	110	0.135	4
Recommendation from my veterinarian	245	157	88	0.108	5
I can include vaccine in existing vaccination routine	205	119	86	0.106	6
Through vaccination my farm is less exposed to E. coli	193	136	57	0.070	7
My reputation as a cattle producer is at risk	157	172	-15	-0.018	8
Duration of immunity is greater than 6 months	160	203	-43	-0.053	9
Beef products can be traced to my farm	165	213	-48	-0.059	10
Feedlots providing booster assurance	83	286	-203	-0.250	11
My neighbours adopting E. coli vaccine	51	348	-297	-0.366	12
Government recommending use of vaccine	55	482	-427	-0.526	13

Table 5.2 presents a simple ranking of incentives. To understand the extent to which one incentive was more influential than another, the B-W scores are standardized to probabilistic ratio or interval scales. This allows the *relative* importance/influence of the incentives to be meaningfully analyzed. To recall, the Sqrt (B-W) in Table 5.3 for all the presented incentives is scaled by a factor such that the most influential incentive that has the highest Sqrt (B-W) takes the interval scale of 100 in this case “my buyer requiring use of an E. coli vaccine as part of

production protocol as a condition for accepting my calves/cattle". All other incentives are compared relative to the high ranking interval. After the B-W scores were transformed into a standardized sqrt interval scale, the ranking in relation to the most important/influential incentive changed. The incentive "my buyer requiring use of an E. coli vaccine as part of production protocol as a condition for accepting my calves/cattle" based on the standardized interval scale became the most influential incentive with other top five incentives shifting rank[16] within this echelon, as shown in Table 5.3. This was followed by "subsidy to compensate the costs of my adoption of the vaccine is available through a government funded vaccination" and then "premiums for E. coli vaccinated cattle are available through various programs (e.g. branded beef program) within the supply chain". On the other end of the spectrum, the least influential incentives remained unchanged.

As noted earlier, the standardized interval scale allows for a more meaningful interpretation and cross comparison of incentives relative to the most important/influential incentive. The incentive "my buyer requiring use of an E. coli vaccine as part of production protocol as a condition for accepting my calves/cattle" is the most influential incentive while "government recommending use of E. coli vaccine" is the least influential incentive taking into account all producer responses across the entire sample. Bearing this result in mind, the results show that incentives such as "subsidy to compensate the costs of my adoption of the vaccine is available through a government funded vaccination program" and "premiums for E. coli vaccinated cattle are available through various programs (e.g. branded beef program) within the supply chain" are 0.97 times as influential to producers as "my buyer requiring use of an E. coli vaccine as part of production protocol as a condition for accepting my calves/cattle" (Table 5.3). The attraction of new sets of buyers as an incentive to adoption is 0.60 times as influential as "my buyer requiring use of an E. coli vaccine as part of production protocol as a condition for accepting my calves/cattle". Such a result, together with the relatively low influence of the incentives "government recommending use of E. coli vaccine", "my neighbours (other cattle producers) are adopting the E. coli vaccine" and "feedlots providing an assurance that they will give my cattle a

[16] The intuition behind this change is that the SQRT B-W utilizes the formula total best/total worst. The incentive my buyer requiring use of vaccine received the least amount of worst counts which aided in this incentive yielding the highest SQRT B-W, becoming the most influential incentive and therefore the reference incentive.

booster of the E. coli vaccine to maintain immunity of my cattle", are thought-provoking outcomes. Thus incentives that are not concerned with market/supply chain dynamics which can allow for growth opportunities as a result of adoption do not appear to be very influential.

The standardized interval scale also reveals key information on the relative importance of these incentives. A closer inspection of the results shows a large drop between the third and fourth incentives, which highlights the relative equal importance of the top three incentives that were identified as being suitable for broader targeting given their homogeneity amongst respondents. Furthermore, the fourth through to the seventh incentives are also of similar importance although respondents did not uniformly agree on their importance as shown by the heterogeneity of the incentives. This pattern of results continues, with incentives eight to ten showing similar importance, followed by the last three which are much lower compared to the most important incentive.

Table 5.3: BWS Relative Importance and Heterogeneity Summary Statistics

Incentive	Mean of Individual B-W	Var of Individual B-W	Stdev of Individual B-W	Stdev/ Mean	Sqrt B-W	Standardized Sqrt Interval Scale (Relative Importance)	Ranking based on Standardized Scale	Ranking based on Standard Score
My buyer requiring use of vaccine as part of production protocol	1.28	2.79	1.67	1.30	2.21	100.0	1	3
Subsidy to compensate costs of adoption	1.38	3.50	1.87	1.36	2.15	97.4	2	2
Premiums available through programs	1.51	3.53	1.88	1.24	2.15	97.2	3	1
Attraction of new buyers for vaccinated cattle	0.54	3.85	1.96	3.62	1.34	60.6	4	4
I can include vaccine in existing vaccination routine	0.42	2.97	1.72	4.07	1.31	59.4	5	6
Recommendation from my veterinarian	0.43	4.22	2.05	4.74	1.25	56.5	6	5
Through vaccination my farm is less exposed to E. coli	0.28	2.14	1.46	5.21	1.19	53.9	7	7
My reputation as a cattle producer is at risk	-0.07	3.00	1.73	-23.43	0.96	43.2	8	8
Duration of immunity is greater than 6 months	-0.21	3.27	1.81	-8.54	0.89	40.2	9	9
Beef products can be traced to my farm	-0.24	3.64	1.91	-8.07	0.88	39.8	10	10
Feedlots providing booster assurance	-1.00	2.52	1.59	-1.59	0.54	24.4	11	11
My neighbours adopting E. coli vaccine	-1.46	3.14	1.77	-1.21	0.38	17.3	12	12
Government recommending use of vaccine	-2.10	3.02	1.74	-0.83	0.34	15.3	13	13

Notes: Column 2 aggregated B-W score/No. of observations (203). Column 3, variance of individual B-W scores. Column 4, Standard deviations of individual B-W scores. Column 5, Standard deviation of individual scores/mean of individual scores. Column 6, square root of total best/total worst. Column 7, see BWS analysis for detailed explanation.

To summarize, the influence/preference analysis of the 13 identified incentives, shows that cow-calf producers respond to the presence of incentives to different degrees. The results point towards cow-calf producers being more driven, above all, by market/supply chain oriented incentives, as well as financial support/guarantees in the form of government subsidies in order to increase their willingness to adopt the E. coli vaccine technology. Also, taking the standardized ratio scale structure into account, supply chain co-ordination represented by "my buyer requiring use of an E. coli vaccine as part of production protocol as a condition for accepting my calves/cattle", "premiums for E. coli vaccinated cattle are available through various programs (e.g. branded beef program) within the supply chain", and "attraction of new sets of buyers" appear to be particularly important in incentivizing cow-calf producers to adopt the E. coli vaccine. It should be noted however, that such supply chain co-ordination efforts would need to be initiated by downstream supply chain participants in order for cow-calf producers to be more receptive toward the inclusion of such food safety improvement initiatives. This reinforces the notion that producers respond to market pressures and incentives from downstream participants.

5.8. BWS Choice Heterogeneity Analysis

Although the initial results of the BWS give a clear indication as to which incentives are considered to be the most and least influential by the respondents as a whole, the exploration of preference/influence heterogeneity provides further insights. As noted by Adamsen et al. (2013), the initial case 1 of B-W analysis does not capture any heterogeneity that might be present in the data. The calculations of the variance, more specifically the standard deviation of the individual BWS scores, can be used to ascertain whether the choices of cow-calf producers were selected consistently or whether they are heterogeneous across the sample.

As is observable in Table 5.3, all 13 incentives have standard deviations above 1 which is an indication of the existence of respondent heterogeneity in their response to the incentives. To establish the extent of heterogeneity in producer preferences, the individual standard deviation to individual mean of B-W score ratio is utilized (Stdev/Mean). High absolute ratios of Stdev/Mean suggest greater heterogeneity, whereas absolute ratios that are equivalent to zero or close indicate total or more agreement in the degree of influence respectively. From Table 5.3 it can be seen that the incentives with lower Stdev/Mean ratios tend towards homogeneity, meaning that cow-calf producers were for the most part in agreement as to the relative influence or non-influence of these particular incentives.

These incentives include: (“premiums for E. coli vaccinated cattle are available through various programs (e.g. branded beef program) within the supply chain”, “government recommending use of vaccine”, “my neighbours (other cattle producers) are adopting the E. coli vaccine”, “subsidy to compensate the costs of my adoption of the vaccine is available through a government funded vaccination program”, and “my buyer requiring use of an E. coli vaccine as part of production protocol as a condition for accepting my calves/cattle”). On the other hand, other incentives such as (“beef products from my calves/cattle can be traced back to my farm”, “recommendation from my veterinarian to use the E. coli vaccine in my operations”, “my reputation as a cattle producer is at risk because of higher consumer expectations concerning food safety”, “I can include an E. coli vaccination in my existing vaccination routine”, “attraction of a new set of buyers for my vaccinated cattle”, “duration of immunity for calves/cattle is greater than 6 months”, and “through vaccination, my farm is less exposed to the effects of E. coli outbreaks such as beef recalls and supply disruptions at packing plants”) all have Stdev/Mean ratios well above 1 strongly indicating substantial heterogeneity among cow-calf producer responses regarding the relative importance or influence of these incentives to the adoption of the vaccine.

Muller and Rungie (2009) suggest that special attention should be paid to attributes that show a high degree of heterogeneity and reasonable influence as they imply significant importance to a subset of respondents, even though these incentives may not be important to all respondents. Thus incentives which have a low mean B-W score but high degree of heterogeneity such as “my reputation as a cattle producer is at risk because of higher consumer expectations concerning food safety” with an individual mean of (-0.07) and Stdev/mean ratio of (-23.43) are suitable for narrow targeting, particularly if policy makers want to spur adoption of food safety initiatives such as the E. coli vaccine from smaller segments of cow-calf producers. Taking into consideration that the adoption of the E. coli vaccine is currently voluntary in nature, this suggests that some cow-calf producers may not deem it necessary to adopt. Therefore, one-size-fits all type of strategies may not be effective. Thus more efficient targeting or differentiated policies for sub-groups of producers may be more appropriate.

On the other hand, heterogeneity can present challenges for policymakers and industry strategists in broadly targeting incentives from the standpoint that widespread adoption of the E. coli vaccine may be preferred. Therefore, incentives that are more homogeneous amongst cow-calf producers could be ideal for broader targeting. These incentives included: “my buyer requiring use of an E. coli vaccine as part of production protocol as a condition for accepting my calves/cattle” with a Stdev/mean ratio of (1.30), and “subsidy to compensate the costs of my adoption of the vaccine is available through a government funded vaccination program” (1.36), “premiums for E. coli vaccinated cattle are available through various programs (e.g. branded beef program) within the supply chain” (1.24). On the other end of the scale, homogeneity was also found to be present in the bottom three ranking incentives which included: “feedlots providing an assurance that they will give my cattle a booster of the E. coli vaccine to maintain immunity of my cattle” (1.59), “my neighbours (other cattle producers) are adopting the E. coli vaccine” (1.21), and “government recommending use of E. coli vaccine” (0.83). This suggests that these set of incentives may be suitable for broader targeting for purposes of achieving wider adoption of the E. coli vaccine, however, producer buy-in would not be strong. As noted in section 4.8 of the methodological chapter, the Stdev/mean ratio signals the possible existence of sub-sections of producers that are homogenous within their sub-group and heterogeneous across other sub-groups. A Latent Class cluster analysis is performed to identify unique classes/segments of cow-calf producers within the data set.

5.9. Latent Class Analysis

Latent Class cluster analysis was discussed in the methodology chapter of this thesis. Coltman et al. (2011), summarizing this approach, note that LC analysis enables one to derive a maximum likelihood based statistical model that accounts simultaneously for both the similarity and differences between individuals or firms. Furthermore, the authors state that this method also allows one to: (1) classify subtypes of related cases based on unobserved (latent) heterogeneity, (2) estimate posterior probabilities that a specific individual/firm falls into a particular class, and; (3) include exogenous variables (covariates) to enable simultaneous segment classification and description.

With the empirical estimation of the latent class model the aim is to assess what type of cow-calf producers prefer each of the incentives and how the social, economic, geographical and locus of control considerations influence their choices. Several models were estimated in order to select the optimal number of unique classes/segments within the data. Beyond the estimation of five classes, degrees of freedom became negative and thus five classes was considered to be the upper threshold of segments for this dataset.

The process that was used to formally identify the number of classes or segments present in the data was based on the information criteria scores. As a general rule, the lower the value, the better the model fit. According to Coltman et al. (2011) information criteria scores are derived by assessing the degree of improvement in explanatory power adjusted by degrees of freedom. Although the most commonly used information criteria are the Akaike information criterion (AIC) and the Bayesian information criterion (BIC), in similar style to Coltman et al. (2011), this study opted to use the consistent Akaike information criterion (CAIC) and the Akaike information criterion 3 (AIC3) as these criteria are considered to yield more conservative estimates. This is from the premise that these criteria factor in parsimony by penalizing the Log-Likelihood goodness-of-fit values to account for the number of parameters in the model (Coltman et al., 2011). Table 5.4 contains the classification statistics including the Log-Likelihood value, number of parameters and classification errors. These estimates are commonly employed in order to select the optimal number of classes in addition to the information criteria.

Table 5.4: Measure of Model Fit and Parsimony by Latent Class Cluster

	Number of Segments				
	1	2	3	4	5
Log Likelihood	-5071	-5022	-4993	-4965	-4938
Bayesian Information Criteria	10679	10693	10745	10800	10860
Akaike Information Criteria (AIC)	10345	10288	10272	10257	10247
Akaike Information Criteria 3 (AIC3)	10446	10410	**10415**	10421	10432
Consistent AIC (CAIC)	10780	10815	**10888**	10964	11045
Number of parameters	101	125	149	173	197
Degrees of Freedom	102	78	54	30	6
Classification Error	0.000	0.08	0.09	0.09	0.105

The interpretation of the statistics contained in Table 5.4 follows. All the statistics are assessed collectively to ensure that the final choice of number of unique segments is an accurate fit to the data. The Log-Likelihood statistic, similar to the information criteria, should be low to indicate a good model fit. A closer look at the AIC3 and CAIC shows an increase of these statistics beyond the third segment, a pattern used in determining the ideal class fit. It is worth mentioning that a two cluster solution based on these information criteria statistics seemed ideal, yet, a review of the probability loadings on each incentive changed this conclusion as the loadings were positive and negative duplicates of each other. The number of parameters is also of considerable importance, as models with fewer numbers of parameters are considered a better fit as noted by Coltman et al. (2011). In this instance, compared to the four and five cluster solutions, the three cluster solution has a lower number of parameters (149). Finally, the classification error for segment three was (0.09), the same as the four cluster solution and better than five clusters. Again, the lower the classification error, the better the model fit.

Based on the magnitude of the AIC3 and CAIC statistics, as well on the criteria of parsimony, classification error and probability loadings distribution, the results of the Latent Class cluster analysis reveal the existence of three unique classes/segments of cow-calf producers. As can be observed in Table 5.5, the relative influence of producer incentives differs across segments with each cluster influenced differently by the incentives. Furthermore, several covariates were found to be significant in determining class membership. In the following discussion, the terms class, cluster and segments are synonymous and as such these terms are used interchangeably.

As discussed in section 4.8 the covariates included in the Latent Class estimation were gender, age, education, years as principal decision maker, years planning on continuing as a cow-calf producer, percentage of sales/revenues derived from cow-calf operations, importance of cow-calf operations to livelihood, province, and locus of control. The selection of these characteristics follows the literature where empirical studies have utilized similar socio-demographic and behavioural characteristics to determine the class membership of individuals or firms in latent class analysis.

In order to facilitate discussion, the three clusters were given names based on the incentives that appear to be influential in these segments. Cluster 1 was more influenced by market/supply chain oriented incentives, cluster 2, production protocol incentives, and cluster 3 was influenced by incentives that relate to risk aversion. Table 5.5 shows the probability of cow-calf producers falling within each of the three clusters (class size), 58%, 24% and 18% respectively, as well the probabilities of the 13 incentives being selected as influential in each of the three clusters/segments.

Table 5.5: Characteristics of Latent Class Clusters

Class Size	Cluster1 Market/Supply Chain 58%		Cluster2 Production Protocol 24%		Cluster3 Risk Averse 18%	
	Most Influential Incentives	**Prob.**	**Most Influential Incentives**	**Prob.**	**Most Influential Incentives**	**Prob.**
Most	Attraction of new sets of buyers	0.42	Duration of immunity > 6 months	0.89	Beef products can be traced to my farm	0.52
2nd	My buyer requiring use of vaccine	0.39	Feedlots providing assurance	0.21	My reputation as cattle producer is at risk	0.26
3rd	Premiums for E. coli vaccinated cattle available	0.34	My neighbours adopting the vaccine	0.20	Government recommending use of vaccine	0.14
4th			I can include vaccine as part of existing vaccination routine	0.19	My neighbours adopting the vaccine	0.13

Cluster 1, the market/supply chain cluster, with a 58% class probability, represents the largest group of respondents. Attraction of a new set of buyers for vaccinated cattle and "my buyer requiring use of vaccine as part of production protocol as a condition for accepting my calves/cattle" are the two most influential incentives, followed by "premiums for E. coli vaccinated cattle are available through various programs (e.g. branded programs) within the supply chain". Thus, a significant portion of cow-calf producers prefer incentives that can translate to growth opportunities.

Cow-calf producers in this segment can be said to be mainly characterized by downstream supply chain/market oriented incentives, as indicated by the higher probability loadings on the most influential incentives in this segment. The notion of supply chain co-ordination is fairly strong among respondents in this cluster, with producers more likely to be influenced by market/supply chain type incentives in their decision to adopt the E. coli vaccine.

The adoption incentives that are most influential in cluster 2 (24% class probability) are more production protocol oriented. This segment of producers place the most emphasis on "duration of immunity for my calves/cattle is greater than six months" and "feedlots providing an assurance that they will give my cattle a booster of the E. coli vaccine to maintain immunity of my cattle". This is followed by "my neighbours (other cattle producers) are adopting the E. coli vaccine" and "I can include an E. coli vaccination in my existing vaccination routine".

This particular class of cow-calf producers can be considered to be assurance seekers. They are driven or influenced by incentives that guarantee that their initial investment in the E. coli vaccine technology is safeguarded, as seen in the higher probability loadings on the incentives mentioned above. The significant influence of these particular incentives in this segment particularly "my neighbours (other cattle producers) are adopting the E. coli vaccine" might be interpreted as a way to use another producer's learning curve to become more efficient and effective once the decision of adoption is finally made.

Following from the theoretical considerations chapter, including the Tragedy of Anti-Commons, if neighbours are adopting the E. coli vaccine, there is more assurance that if a cattle producer utilizes the same pool of feedlots and retains ownership of their cattle, exposure to E. coli risk is reduced. What is interesting is that these producers were less likely to be motivated by incentives that represent supply chain co-ordination dynamics. This therefore signals that guarantees regarding vaccine efficacy and the production characteristics of the technology in this class of producers take precedence over supply chain co-ordination incentives. For this cluster of cow-calf producers, technological change policies which focus on improving ease of use and ease of adoption into existing production protocols, allowing adoption of the E. coli vaccine to be made less expensive or to be included within existing BMP programs may be effective.

Cluster 3, with a class probability of 18%, rates "beef products from my calves/cattle can be traced back to my farm" as the most important/influential incentive, followed by "my reputation as a cattle producer is at risk because of higher consumer expectations concerning food safety", "government recommending use of E. coli vaccine for cattle" and "my neighbour (other cattle producers) are adopting the E. coli vaccine". This particular class can be said to be characterized as risk-averse from the perspective that cow-calf producers in this segment are more influenced by incentives relating to E. coli risk in relation to exposure to their farming operations. These producers are concerned about their reputations as farmers being at risk as a result of potential E. coli outbreaks, which can lead to beef recalls and possible supply chain disruptions as well as liability risks.

Overall, due to positive externalities/public good attributes, and information asymmetry as a result of the pooling effect discussed in Chapter 3, the under-production of the E. coli vaccine has led to an incomplete market as a result of market failure. This concept of an incomplete market can be addressed through various incentives that have been found to motivate cow-calf producers in their respective unique segments. The influence of these incentives can therefore be viewed as mirror images of the issues that cow-calf producers in these segments might be concerned about prior to their adoption decisions. The creation of such incentives may serve in stifling the current market failure, however, these incentives are currently not available hence the failure of the market to produce vaccinated cattle. For example, in the case of cluster 1, putting mechanisms in place in the form of governance structures that are able to identify new markets and define production protocols that meet buyer needs, which then may create avenues for premiums to be established that can perhaps address the market failure situation if brought on stream.

5.10. Covariates

A total of 10 covariates were utilized in the Latent Class cluster analysis. Out of these 10 covariates, 4 were found to be statistically significant and thus provide further insight into the three unique producer segment/classes identified in the data. These covariates include: age, duration as a principal decision maker, sales/revenues generated from cow-calf operations, and external locus of control. This significance is evidenced by the p-values and high Wald statistics shown in Table 5.6. The variables that were not significant in explaining class membership included gender, education, continuity as cow-calf producer, and the province of operation. The significant covariates will now be discussed in the context of the three producer classes. Table 5.8 shows the probability loadings of the significant covariates by cluster.

Table 5.6: Significant Covariates

Covariates	Wald	p-value	
Gender	0.18	0.91	n.s.
Age	6.14	0.046	**
Education	1.06	0.59	n.s.
Duration as principal decision maker	5.36	0.068	*
Continuity	3.41	0.18	n.s.
Sales/Revenues	6.89	0.032	**
Livelihood	0.64	0.73	n.s.
Province	3.06	0.22	n.s.
Internal Locus	0.20	0.91	n.s.
External Locus	8.69	0.013	***

* $p<0.1$, ** $p<0.05$, *** $p<0.01$

5.10.1. Age

This variable, although collected as actual age in the survey, was re-coded into a categorical variable in order to preserve degrees of freedom in the latent class analysis estimation. These categories took the form of a count variable, with 1 representing cow-calf producers in the age range 25-34 years, 2 for ages 35-44 years, 3 for ages 45-54 years, 4 for ages 55-64 years, and 5 for producers older than 64 years. Age was found to be a significant covariate at the 5% level of significance, as shown in Table 5.6. As can be seen in Table 5.7, producers who fell in the 25-34 age category were more likely to belong to cluster 1 or 3 with slightly differing probabilities. This perhaps can be taken as young cow-calf producers seeking greater opportunities for growth, but given less experience, are also likely to be more risk-averse as they learn the cow-calf business. As the age range advances, the probability of producers belonging to segment/cluster 1 increased, with a noticeable change in those producers greater than 64 years. This age category was split, with 51% and 42% likely to belong in segments 1 and 2 respectively. Overall, those producers that range between the ages of 35 to 64 are likely to belong to cluster 1, which is dominated by downstream supply and market oriented incentives.

Table 5.7: Probabilities of Significant Covariates by Class Cluster

Covariates	Cluster1	Cluster2	Cluster3
	Prob.	Prob.	Prob.
Age			
25-34 years	0.43	0.24	0.33
35-44 years	0.64	0.06	0.30
45-54 years	0.67	0.20	0.13
55-64 years	0.56	0.24	0.20
>64 years	0.51	0.43	0.06
Principal Decision Maker			
Less than 4 years	0.33	0.12	0.55
5-20 years	0.75	0.13	0.12
21-35 years	0.65	0.19	0.16
35 years and over	0.41	0.37	0.22
Sales/Revenues			
0-24%	0.53	0.12	0.34
25-49%	0.58	0.26	0.16
50-79%	0.62	0.27	0.11
80-100%	0.62	0.37	0.01
External Locus			
Completely disagree	0.63	0.10	0.27
Somewhat disagree	0.58	0.19	0.23
Neutral	0.62	0.23	0.15
Somewhat agree	0.44	0.42	0.14
Completely agree	0.0009	0.98	0.02

5.10.2. Duration as Principal Decision Maker

This particular variable was collected as a categorical variable in the producer survey. With category 1, representing producers with less than 4 years as principal decision makers, 2 for 5-20 years of experience, 3 for 21-35 years and lastly, 4 for producers with 35 years and over as principal decision makers. The duration as a principal decision maker in the cow-calf operations was found to be significant at the 10% level of significance as seen in Table 5.6. Cow-calf producers that have less than 4 years of experience were more likely to belong to segment/cluster 3, at 55%, which suggests this segment may be more attuned to reputation-based incentives and thus are more risk averse given the duration as principal decision makers. In the 6-10 and 10-25 year categories, the probability of cow-calf producers belonging to segment/cluster 1 and 2 is 74% and 64% respectively. For those producers with more than 35 years as principal decision makers, there is almost an equal split in their probabilities to belong to both segment 1 or 2 at 41% and 37% respectively. Similar to age, a possible interpretation would be that producers in this category have enough experience to also see value in selecting incentives that provide assurance in the adoption process as they endeavor to achieve efficiency and maximize profitability.

5.10.3. Sales/Revenues

In relation to percentage of sales/revenues derived from cow-calf operations, this particular covariate was significant at the 5% level as shown in Table 5.6. Observing from Table 5.7, it can be seen that as the level of sales/revenues from cow-calf operations increases, the probabilities of producers belonging to cluster 1 also increases. This similar pattern is also observed in cluster 2, with those producers having sales/revenues from cow-calf operations of 80-100% having a 37% probability of belonging to segment 2. This result suggests that as the cow-calf operations become the mainstay of producers, the importance placed on growth opportunities and supply chain co-ordination increases. This takes place in tandem with their investment protection awareness, resulting in producers seeking incentives that are more assurance motivated. Segment 3 on the other hand shows the reverse effect, with the probability decreasing as dependency on operations increases.

5.10.4. Locus of Control

The two locus of control variables included as covariates in the Latent Class cluster analysis were created from the seven locus of control questions included in the Canadian cow-calf producer survey as seen in Table 5.8. These variables were measured in the form of a Likert scale, with 1 indicating a respondent being completely in disagreement with the locus statements, and 5 completely in agreement (see survey question 29: a, b and d) for internal loci and external loci (c, e and f). A priori, the locus questions were categorized into internal and external loci and thus those questions representing internal loci and external loci were transformed into single variables through an average calculation. The internal locus control questions were summed and averaged by the number of questions (locus (a) + locus (b) + locus (d)/3 to yield a single variable. A similar transformation was done for the external locus of control (locus(c) + locus (e) + locus (f))/3 to produce a single variable. A factor analysis was considered, however, taking into account degrees of freedom considerations in the cluster analysis, categorical variables were deemed to be more effective rather than continuous variables, as they take less degrees of freedom. Furthermore, the interpretation of the factored variable was not clear, as it was not clear how to interpret the internal and external aspect of the variable. The external locus of control was found to be significant at the 1% level as shown in Table 5.6.

Table 5.8: Locus of Control Questions

Internal Locus of Control
I feel in control of potential E. coli contamination due to my existing management practices/interventions
Whether or not I'm successful in mitigating/controlling E. coli depends mostly on my own ability
To a great extent E. coli incidences on my cow-calf operation are determined by the management practices I have in place
External Locus of Control
My success as a cow-calf operator depends mostly on luck
It is not advisable for me to plan too far ahead by enhancing my current management practices because E. coli incidences are such that they cannot be fully prevented.
To a great extent E. coli incidences on my cow-calf operation are determined by factors beyond my control

As shown in Table 5.7, for those cow-calf producers that completely disagreed that E. coli incidences on their farms are outside of their control, 63% belonged to segment/cluster 1. This trend continued through the middle categories where most of the producers aligned to segment/cluster 1 until the somewhat agree category. At this point there was approximately an even split with 43% and 42% of cow-calf producers belonging to cluster 1 and cluster 2 respectively. A more interesting result shows that for those cow-calf producers that were completely agreed that E. coli outbreaks on their farms was beyond their control, 98% were likely to belong to segment/cluster 2. This result is consistent with the assurance nature of this segment of cow-calf producers who strongly believe that E. coli risk on their farms is beyond their control. In the absence of assurance like incentives, these producers are less likely to adopt the E. coli vaccine as they believe the E. coli pathogen is not within their capacity to control. The following section assesses the determinants of a producer's willingness to adopt an E. coli vaccine using Probit analysis.

5.11. Probit Analysis

A Binary Probit model was estimated to examine the determinants that may affect a cow-calf producer's willingness to adopt the E. coli vaccine. As discussed in chapter 4, a variation of an anchored Best-Worst Scaling was employed in the Canadian cow-calf producer survey where, after the completion of the 13 choice sets, producers were probed with a follow-up question based on the incentives that had been presented: "would you consider adopting an E. coli vaccine if presented with incentives such as some of those appearing above?". The answers were ordered into three categories of "yes", "don't know/unsure" and "no" responses and represent the dependent variable in the binary and Ordered Probit analyses. The number of respondents that indicated yes was 145, this followed by 50 for those unsure and 8 for no responses. In order to estimate the Binary Probit model, the dependent variable was transformed into a dummy variable, where the "yes" responses were transformed to 1 and 0 otherwise. All estimations were conducted using STATA 2013.

A total of 32 variables were estimated in the Binary Probit model (see Table 5.9), with 13 of these variables representing the 13 identified incentives that were presented to surveyed producers in a series of 13 repeated choice sets (see Table 4.4). These incentives were included in the model to confirm the extent to which they explain the adoption decision. Socio-demographic characteristics were also included to control for the effect of gender, age, level of education, location (Alberta and Manitoba with Saskatchewan omitted as a reference variable), dependence on cow-calf operations for livelihood, number of years a principal decision maker, continuity as a cow-calf producer and the percentage of sales/revenues derived from cow-calf operations. Other variables expected to affect willingness to adopt the vaccine included:

producer awareness of the E. coli vaccine technology, perception of responsibility regarding E. coli reduction[17], retaining of ownership of cattle, size of operation, and locus of control. These variables were added to the estimation equation (15) in chapter 4 on the premise that they can potentially explain a producer's willingness to adopt. Table 4.7 in chapter 4 provides details on the definitions of each of the included variables together with how these variables are measured. Table 5.9 presents the results of the Binary Probit model estimations.

The Binary Probit model results shown in Table 5.9 suggest that 20 out of 32 estimated variables are important/influential predictors of a cow-calf producer's willingness to adopt the E. coli vaccine. These variables include a producer's level of education, awareness of technology, perception of responsibility; attitude surrounding the external locus of control, and all the 13 incentives captured by the individual B-W scores. As shown in Table 5.9, the p-values indicate that these variables, excluding the 13 incentives for now, are significant at the 1%, and 5% respectively. The individual B-W scores on the other hand, are mostly significant at the 1% level of significance with the exception of "subsidy to compensate the cost of my adoption of the vaccine is available through a government funded vaccination program,", "government recommending use of E. coli vaccine", "attraction of a new set of buyers, and "I can include vaccine in an already existing vaccination routine" which are significant at the 5% level. The pseudo R-squared shows the goodness of fit of the data to the model. The results indicate that the Binary Probit model has a better fit to the data, with a pseudo R-squared of 23.4% compared to that of 19.4% for the Ordered Probit model which is reported in Appendix 2.

[17] Perception of primary responsibility for reducing E. coli is comprised of dummy variables created for each of the categories given the difficulty of interpreting an aggregated coefficient. It should be noted that due to co-linearity concerns, the first category dummy variable (cow-calf producers) was omitted and thus serves as the reference variable. Furthermore, the fifth category dummy variable (retailers) did not receive any responses hence its omission from the model.

Table 5.9: Binary Probit Model with all estimated variables included
(Dependent variable – willingness to adopt)

Variable	Coefficient	Std. Err.	P value
Gender	0.354	0.314	0.260
Age	0.017	0.018	0.344
Level of education	0.672***	0.241	0.005
Awareness of technology	0.473**	0.238	0.047
Primary Responsibility of E. coli reduction - Feedlots	-1.479***	0.501	0.003
Primary Responsibility of E. coli reduction – Processors/Packers	-0.824**	0.427	0.054
Primary Responsibility of E. coli reduction - Consumers	-1.674***	0.571	0.003
Primary Responsibility of E. coli reduction - Regulators	-1.662**	0.627	0.008
Retain ownership of cattle	-0.014	0.238	0.995
Size of operation	0.000	0.000	0.561
Importance of operations to Livelihood	0.371	0.293	0.206
Experience as principal decision maker	-0.014	0.018	0.425
Alberta	-0.181	0.276	0.513
Manitoba	-0.241	0.332	0.467
Perception of benefits	0.002	0.311	0.993
Continuity as a cow-calf producer	0.008	0.019	0.656
Sales/Revenue derived from operations	0.000	0.005	0.994
Internal Locus of control	0.033	0.152	0.827
External Locus of control	-0.373**	0.170	0.028
Beef products can be traced to my farm	1.043***	0.323	0.001
Premiums available through branded programs	0.927***	0.314	0.003
Recommendation from my veterinarian	0.883***	0.313	0.005
Subsidy to compensate cost of adoption available	0.862***	0.310	0.005
Government recommending use of vaccine	0.791**	0.308	0.010
My reputation as producer is at risk	0.877***	0.304	0.004
My buyer requiring use of vaccine	0.935***	0.316	0.003
Feedlots providing assurance for a booster	0.951***	0.313	0.002
Duration of immunity greater than 6 months	0.918***	0.316	0.004
Through Vaccination I can reduce supply disruptions	0.960***	0.319	0.003
My neighbours adopting vaccine	0.866***	0.305	0.005
Attraction of a new set of buyers	0.756**	0.300	0.012
I can include vaccine in an existing vaccination routine	0.885**	0.326	0.006
_cons	0.586	1.309	0.654
N	203		
Pseudo R-sq.	0.234		

* p<0.1, ** p<0.05, *** p<0.01

An Ordered Probit model was also estimated, where the dependent variable took the order of the three categories of "yes", "don't know/unsure" and "no" responses. The categorical nature of this dependent variable allowed for the marginal effects of each sub-group of producers to be examined in relation to the drivers of their adoption decisions. Results for the Ordered Probit model are provided in Appendix 2. As seen in Table A2.1 and A2.2 in the appendix, this model performs comparably to the Binary Probit model, however, this particular model also allowed for additional information to be examined due to the categorical nature of its dependent variable. In comparison to the Binary Probit model, the Ordered Probit model was able to show the effect of the explanatory variables on willingness to adopt for the sub-groups of producers who indicated that they didn't know or were unsure; those that stated they would not be willing to adopt the vaccine despite the presence of incentives (see Table A2.3, Table A2.4 and Table A2.5) in Appendix 2. Following the estimation of the Binary Probit model inclusive of all variables, the insignificant variables were dropped from the model. This reduced model is preferred in order to dampen the effects of the insignificant variables and thereby produce more robust marginal effects estimations. These results are presented in Table 5.10.

Table 5.10: Binary Probit Model with Significant Variables
(Dependent variable – willingness to adopt)

Variable	**Coefficient**	**Std. Err.**	**P value**
Level of education	0.639***	0.228	0.005
Awareness of technology	0.522**	0.228	0.022
Primary responsibility for E. coli reduction – Feedlots	-1.391***	0.489	0.004
Primary Responsibility of E. coli reduction – Processor/Packer	-0.807*	0.418	0.054
Primary Responsibility of E. coli reduction - Consumers	-1.497**	0.550	0.007
Primary Responsibility of E. coli reduction - Regulators	-1.599**	0.611	0.009
External Locus of control	-0.379**	0.152	0.013
Beef products can be traced to my farm	0.882***	0.297	0.003
Premiums available through branded programs	0.787***	0.288	0.006
Recommendation from my veterinarian	0.759***	0.290	0.009
Subsidy to compensate cost of adoption available	0.717**	0.284	0.012
Government recommending use of vaccine	0.673**	0.286	0.018
My reputation as producer is at risk	0.766***	0.284	0.007
My buyer requiring use of vaccine	0.785***	0.292	0.007
Feedlots providing assurance for a booster	0.857***	0.293	0.003
Duration of immunity greater than 6 months	0.800***	0.293	0.006
Through Vaccination I can reduce supply disruptions	0.841***	0.295	0.004
My neighbours adopting vaccine	0.737***	0.282	0.009
Attraction of a new set of buyers	0.650**	0.279	0.020
I can include vaccine in an existing vaccination routine	0.763**	0.297	0.010
_Cons	1.831	0.644	0.004
N	203		
Pseudo R-sq.	0.212		

* p<0.1, ** p<0.05, *** p<0.01

5.12. Marginal Effects

The marginal effect[18] of an independent variable measures the impact of a change in an independent variable (e.g., X_i) on the expected change in the dependent variable (e.g., Y). In other words, marginal effects show the change in probability when the predictor or independent variable increases by one unit.

The marginal effects of the Binary Probit model were estimated using the results in Table 5.10, which included variables that were found to be significant. These marginal effects are presented in Table 5.11. The estimated marginal effect for level of education shows that an increase in a cow-calf producer's level of education at or above the college level compared to less than college education increases the probability of their willingness to adopt an E. coli vaccine by 20.3%. This result suggests that producers with higher levels of formal education may have a better appreciation of food safety technologies such as that of an E. coli vaccine which would thus affects their willingness to adopt.

The impact of a producer's awareness of technology, defined as whether a cow-calf producer has ever heard of an E. coli vaccine bears a positive sign and is significant at the 5% level. The estimated marginal effect show that on average, if producers had heard of or became aware the E. coli vaccine, this would increase the probability of their willingness to adopt by 16.1%.

In the descriptive statistics section, it was shown that almost half of the producers 42% had not previously heard of the E. coli vaccine technology, thus the decision to use this awareness in the probit analysis. The significance of this result suggests that awareness programs where producers can be informed and updated on the food safety technologies available for their use in addressing E. coli may be important. A producer must be aware of a technology first before even considering its adoption. The survey data identified producer associations and veterinarians as important sources of information which may be relevant for designing awareness programs.

[18] Calculation of the marginal effects was done as follows: $Y = \phi\,(\beta_0+\beta_1\chi_1+\beta_2\chi_2+\ldots+\beta_n\chi_n)$, thus $\delta Y/\delta\chi_i = \beta_i\, Ø\,(\beta_0+\beta_1\chi_1+\beta_2\chi_2+\ldots+\beta_n\chi_n)$.

Table 5.11: Binary Probit Model Marginal Effects

Variable	**Dy/Dx**	**Std. Err.**	**P value**
Level of education	0.203	0.074	0.006
Awareness of technology	0.161	0.071	0.024
Primary Responsibility of E. coli reduction – Feedlots	-0.499	0.166	0.003
Primary Responsibility of E. coli reduction – Processor/Packer	-0.232	0.058	0.035
Primary Responsibility of E. coli reduction - Consumers	-0.543	0.151	0.002
Primary Responsibility of E. coli reduction - Regulators	-0.576	0.181	0.001
External Locus of control	-0.115	0.046	0.012
Beef products can be traced to my farm	0.266	0.088	0.003
Premiums available through branded programs	0.238	0.086	0.006
Recommendation from my veterinarian	0.229	0.086	0.008
Subsidy to compensate cost of adoption available	0.216	0.085	0.011
Government recommending use of vaccine	0.203	0.085	0.017
My reputation as producer is at risk	0.231	0.084	0.006
My buyer requiring use of vaccine	0.237	0.087	0.007
Feedlots providing assurance for a booster	0.259	0.087	0.003
Duration of immunity greater than 6 months	0.242	0.087	0.006
Through Vaccination I can reduce supply disruptions	0.254	0.088	0.004
My neighbours adopting vaccine	0.223	0.084	0.008
Attraction of a new set of buyers	0.196	0.083	0.018
I can include vaccine in an existing vaccination routine	0.231	0.089	0.009

The estimated marginal effect for a producer's perception of primary responsibility, i.e. the supply chain participant with whom the producer believes the primary responsibility of reducing E. coli lies, is a categorical dummy variable as noted earlier. Primary responsibility was constructed from the survey question 20, which explored the concept of which supply chain link should be held accountable for having the primary responsibility for reducing E. coli risk. All levels of this categorical dummy variable were found to be significant: primary responsibility – feedlots, consumers, and regulators were found to be highly significant at 1% and bearing negative signs. The other significant variable at the 5% level of significance was primary responsibility - processors/packers which represents processor/packers holding the major responsibility for E. coli risk reduction within the supply chain. These variables are interpreted with respect to cow-calf producers.

The marginal effects in this case indicate that on average, the perception that primary responsibility of E. coli reduction belongs to feedlots relative to cow-calf producers would lead to a decrease in the probability of producers' willingness to adopt by 49.9%. On the other hand, the marginal effect on primary responsibility – processors/packers suggests that the belief that primary responsibility of E. coli reduction lies with processors/packers relative to cow-calf producers would lead to a decrease in the probability of producers' willingness to adopt the technology by 23.2%. In addition, the marginal effect of the perception that primary responsibility lies with consumers relative to cow-calf producers suggests that on average, this would lead to a decrease in producers' willingness to adopt the vaccine by 54.3%. In relation to regulators and the belief that primary responsibility belongs to this group. The marginal effects results imply that on average relative to cow-calf producers, this belief would lead to a decrease in producers' willingness to adopt by 57.6%.

These results imply that the perception of responsibility for E. coli reduction affects the decision of cow-calf producers adopting the E. coli vaccine. They are consistent with the results of cow-calf producers believing that the responsibility of E. coli reduction lies mostly with other supply chain participants in the mid-stream and downstream stages of production as reported earlier. The marginal effects relating to feedlots, consumers and regulators were particularly high which firstly highlights the importance placed on feedlots by cow-calf producers given their contribution towards contamination of ground water systems that usually affect produce and drinking water. Furthermore, the idea that consumers reduce the risks of exposure to E. coli contamination by properly cooking beef products might also explain the higher percentage decrease in the marginal effect when cow-calf producers believe consumers bear the primary responsibility for this reduction. As it pertains to regulators, the belief of responsibility belonging here perhaps can be explained by the influence that regulatory bodies such as the CFIA have, as they can pass and mandate various policies that can shape and re-shape industry norms. These results possibly underscore the importance of responsibility for the reduction of E. coli incidences at each stage of the production process so as to ensure safe food production which would minimize supply and demand disruptions.

The external locus of control, as indicated in the Latent Class cluster analysis, is an aggregate of combination locus questions. The results for this variable, as shown in Table 5.11, imply that on average an increase in a producer's perception that E. coli incidences occurring in their operations are outside of their control would lead to a decrease in the probability of their willingness to adopt by 11.5%. Such a result is consistent with the idea that if cow-calf producers believe E.coli risk is beyond their control, then the adoption of an E. coli vaccine will be lower. This result also highlights the importance of management or intervention techniques that are currently in use by producers, as these might reflect their perception regarding the ability to mitigate E. coli risk within their cow-calf operations.

In relation to the 13 incentives, B-W scores for each respondent related to each incentive were used in the probit estimations. In the Binary Probit marginal effects estimation (see Table 5.11) the positive signs attached to each of the incentives suggests a positive relationship with producer's willingness to adopt which met *a priori* expectations.

In summary, chapter 5 has outlined the results from the analysis of the Canadian cow-calf producer survey. The descriptive statistics confirmed the notion of the perception among producers that the benefits of E. coli adoption flow elsewhere within the supply chain, particularly to consumers and processors/packers, re-affirming the importance of incentives to encourage adoption. In relation to awareness, these statistics also showed that a significant percentage of respondents had never heard of the E. coli vaccine. The BWS analysis revealed that the most influential incentives for the adoption of the E. coli vaccine were related to market/supply chain incentives, indicating a possible market-based solution as a strategy for reversing the current low adoption trend.

A Latent Class analysis indicated the existence of three unique clusters of cow-calf producers motivated by different sets of incentives, offering opportunities for industry stakeholders to take a more targeted approach to adoption. On the other hand, the incentives that were found to be homogeneous can be used to appeal to a wider selection of cow-calf producers thus encouraging wider adoption. The Probit analysis suggested that a producer's level of education, awareness of food safety technologies, perception of primary responsibility for E. coli risk reduction, perception on external locus of control and the 13 identified incentives were all significant in driving a producer's willingness to adopt the E. coli vaccine. These results will be discussed further in chapter 6, where policy and industry implications and conclusions will be drawn.

CHAPTER 6

6. SUMMARY AND CONCLUSIONS

6.1. Introduction

As established in the introductory chapter of this thesis, cattle are considered to be asymptomatic carriers of the E. coli pathogen, meaning they carry the bacterium but their health or productivity is not affected. The use of an E. coli vaccine therefore addresses a potential public health problem as humans are affected by E. coli *O157:H7* through consumption of contaminated beef products. This can lead to minor symptoms such as acute hemorrhagic diarrhea and abdominal cramps, to more severe symptoms that can result in kidney failure and even premature death. This translates to health costs, productivity loss and premature death costs that society would have to incur.

Econiche, the first E. coli vaccine made in Canada, has been available in the market since 2008. However, the uptake amongst Canadian cow-calf producers has been low despite the potential social benefits from this vaccine. This study theorized that due to the benefits of adoption flowing elsewhere to participating supply chain stakeholders, primarily, processors/packers and consumers, producer willingness to adopt the E. coli vaccine was reduced. The study therefore assessed possible incentives that may change this pattern of adoption in terms of their relative influence on producers' adoption decisions. Current barriers to adoption were also evaluated. To recall, the primary objectives of this study were to:

I. Examine the underlying economics of incentives to adopt socially beneficial technologies

II. Explore the barriers that currently exist towards the adoption of the E. coli vaccine

III. Examine whether incentives for adoption could be strengthened through closer supply chain coordination

IV. Discuss the implications for policies to enhance adoption of socially beneficial technologies

Several theoretical frameworks shed light on the low adoption rates of the E. coli vaccine. These included: Market Failure, the Tragedy of the Anti-Commons, and Transaction Cost Economics. Market failure in this instance resulted from the E.coli vaccine possessing public good attributes/positive externalities as well as information asymmetry as a result of quality uncertainty which all led to the under-production of vaccinated cattle, affecting the demand for the E. coli vaccine. The tragedy of the Anti-commons examined the notion of a threshold of adoption being met in order for the full benefits of adoption to be realized. The TCE framework on the other hand was able to identify costs (identity preservation, third party verification and search and information costs) that producers might incur while operating in the current supply chain structure. This framework while identifying these costs, was also able to offer potential solutions to the low adoptions rates through the use of supply chain governance structures that reward the vaccination of cattle such as branded beef programs.

Data for this study was gathered through an online survey focused on cow-calf producers in the Prairie provinces. The information gathered was analyzed using Best-Worst Scaling, Latent Class cluster analysis, and a Binary Probit model. This chapter contains the thesis summary and conclusions. The summary describes the major findings of this study within the context of the objectives identified for this thesis. This is then followed by a discussion of the policy and industry implications and main conclusions. Lastly, this chapter concludes with a brief discussion of the limitations of the study and suggestions for further research.

6.2. Major findings and policy and industry implications

In line with expectations, most producers expected the benefits from vaccinating their cattle and calves against E. coli to flow elsewhere in the supply chain. This assertion was confirmed based on the descriptive statistics regarding the perceived distribution of benefits from the adoption of the E. coli vaccine. Sixty-seven percent of respondents felt that the benefits of vaccinating cattle/calves against E. coli would flow primarily to either consumers or processors/packers rather than to cow-calf producers. This outcome is consistent with the discussion in the theoretical chapter where the potential reasons for low adoption and market penetration of the E. coli vaccine were outlined.

Another major insight from the descriptive statistics was the incorporation of an Environmental Farm Plan (EFP) by approximately 64% of cow-calf producers. The E. coli pathogen, as much as it can be a health threat to consumers through direct consumption of E. coli infected beef, has also affected people through the environment as a result of ground water contamination from farm run-off. The creation of negative externalities that have far wider reaching effects such as the Walkerton, Ontario E. coli outbreak in 2000 is an example. The use of EFPs by the majority of respondents perhaps is an indication of a growing awareness and responsibility regarding the environmental footprints of cow-calf operations.

The existence of an ongoing vaccination routine in the cow-calf operation was established through a series of questions in the survey asking respondents about their current vaccination practices. The major idea here was to examine how an existing vaccination routine affects willingness to adopt the E. coli vaccine. Most producers were found to have an established routine in place. This finding is an important one, particularly in light of an established vaccination routine allowing for a more efficient scale of change.

In relation to awareness of the E. coli pathogen and its related outbreaks, the majority of cow-calf producers were very much familiar with the E. coli bacterium and the consequences of its existence, with cited examples of previous E. coli incidences. An aspect of producer awareness that perhaps warranted deeper investigation was awareness of the E. coli vaccine, where a significant number (42%) of cow-calf producers indicated they had never heard of an E. coli vaccine let alone make use of it within their operations. This particular avenue of producer awareness was utilized as an explanatory variable in the Probit analysis to ascertain its effect on a producer's willingness to adopt an E. coli vaccine. The findings showed a very significant variable that serves as a potentially strong driver of a producer's decision to adopt. The implication of this result is that if a producer is not aware of the availability of certain technologies, their decision or willingness to adopt is made without the availability of full information. In other words, a producer can only adopt a technology of which they are aware. Producer education and awareness campaigns may be important as tools for disseminating information pertaining to food safety technologies such as the E. coli vaccine.

The above findings go hand in hand with the primary sources of information for cow-calf producers which were mostly producer associations and veterinarians, with the latter being the primary information source. These sources of information may have a role to play as a conduit for information about food safety technologies, thereby potentially increasing adoption through increasing of awareness.

In line with the second objective, barriers to adoption that have impeded the current use of the E. coli vaccine as a mitigating strategy to E. coli were examined. The results suggest that producers found issues involving the uncertainty of adoption as the major deterrents to adoption. These uncertainties pertained to the effect of the E. coli vaccine in alleviating food safety concerns, meeting buyer needs, and generating the necessary premiums/pay-offs to recoup investment. These barriers to adoption are such that cow-calf producers would need some form of reassurance as to the post-adoption outcomes of their decisions, thus reinforcing the need to have the appropriate incentives in place.

The Best Worst Scaling analysis revealed the degree of influence of the 13 identified incentives on producers' decisions to adopt the E. coli vaccine. These findings provide useful insights for industry stakeholders and government agencies alike with respect to the solutions that have the strongest potential to increase the use of food safety technologies such as the E. coli vaccine. To recall, amongst the most influential incentives were market/supply chain oriented incentives ("my buyer requiring use of an E. coli vaccine as part of production protocol as a condition for accepting my calves/cattle", "premiums for E. coli vaccinated cattle are available through various programs (e.g. branded beef program) within the supply chain" "attraction of new sets of buyers"). As the Transaction Cost Economics framework suggested in Chapter 3, supply chain governance structures that emerge to reduce the transaction costs related to adoption can take the form of beef branded alliances or beef branded programs.

These governance structures may assist in realizing the market/supply chain incentives that were found to have the strongest appeal to cow-calf producers. These include premiums for cow-calf producers, production protocols that meet potential buyer needs as it relates to vaccination, and attracting of new sets of buyers as potential market-based solutions. In addition, having subsidies in place to compensate the costs of adoption through government vaccination programs was found to be very influential, particularly if premiums are not available currently in the marketplace for vaccinated cattle.

From the BWS analysis, the data also revealed that there was heterogeneity in the choice of the most and least influential incentives. This result suggests the existence of unique classes or segments of cow-calf producers who respond differently to different incentives. To explore these segments, a Latent Class cluster analysis was performed using the Latent Gold 5.0 software which suggests the existence of three distinct segments of cow-calf producers with respect to the influence of the 13 incentives. These producer segments were categorized into three themes defined by the importance or influence of incentives dominating each of the classes: market/supply chain oriented producers; production protocol oriented producers; and risk averse producers.

The probability of cow-calf producers belonging to the market/supply chain incentives oriented group (cluster 1) was 58%. This particular cluster is defined mainly by producers looking for growth opportunities within their operations through taking advantage of supply chain incentives. The production protocol incentives oriented group (cluster 2), representing 24% of producers, consists of producers that seek assurance and are more concerned about the efficacy of the vaccine, and how efficiently the vaccine would fit into their current production system. Finally, the risk averse or producer reputation incentives oriented group (cluster 3), representing 18% of the sample, consists of cow-calf producers that are more risk averse with respect to liability and reputation effects, given the high loadings on incentives involving traceability and reputation.

The implications of these results are such that a one-size fits all strategy or policy to encourage adoption of this type of technology may be difficult to implement. Narrow targeting is a viable option where certain incentives are specifically geared towards a certain group of producers given their strong preference for these incentives. It is clear that currently the vaccine is adopted on a voluntary basis and thus not all producers are likely to adopt. Hence, those willing to adopt may show preference for certain incentives within their respective sub-groups. On the other hand, given that the ideal outcome may be to have widespread adoption of the E. coli vaccine in order for the benefits to be fully realized, broad targeting might be a viable option with respect to those incentives around which producers were more homogeneous.

Homogeneity was found in the attitudes of cow-calf producers around the top three ranked incentives based on the standardized interval scale. These incentives included: “my buyer requiring use of an E. coli vaccine as part of production protocol as a condition for accepting my calves/cattle", "subsidy to compensate the costs of my adoption of the vaccine is available through a government funded vaccination program", and "premiums for E. coli vaccinated cattle are available through various programs (e.g. branded beef program) within the supply chain". This suggests that these set of incentives may be ideal for broader targeting to achieve wider adoption rates of the E. coli vaccine. On the other hand, homogeneity was also found to be present in the bottom three ranked incentives which included: "feedlots providing an assurance that they will give my cattle a booster of the E. coli vaccine to maintain immunity of my cattle", "my neighbours (other cattle producers) are adopting the E. coli vaccine", and "government recommending use of E. coli vaccine". It seems that the use of these types of incentives will not have strong producer buy-in and thus would likely need to be accompanied by an emphasis on monitoring and enforcement to ensure compliance.

The inclusion of covariates in the Latent Class cluster analysis adds further depth to the cluster analysis. Variables such as producer age, number of years as principal decision maker, sales/revenues attributed to operations and perception of external locus of control were all found to be significant predictors of the likelihood of a producer belonging to a particular segment.

The Binary Probit analysis examining the factors affecting willingness to adopt the E. coli vaccine revealed a number of significant determinants. These included producer's level of education, whereby higher levels of education tended to increase the willingness to adopt. These results suggest that producers with higher levels of education may have a better appreciation of food safety technologies. Another variable that was significant in influencing a cow-calf producer's decision to adopt an E. coli vaccine was the perception of who held the primary responsibility for E. coli risk reduction. All of the category dummy variables (feedlots, processor/packers, consumers, and regulators) of primary responsibility relative to cow-calf producers were found to be significant and drivers of a producer's willingness to adopt. These results underline the need for a continuity of effort and vigilance across the entire supply chain so as to reduce instances of E. coli incidences and therefore strengthen the production of safe food.

The external locus of control assessed the extent to which respondents believed controlling E. coli risks on their cow-calf operations lay beyond their control. The negative sign attached to this variable was consistent with the idea that if producers perceive the control of E. coli incidences as being beyond their reach, then their willingness to adopt the vaccine decreases. The perception of the E. coli risk as either internal or externally determined therefore is very important in influencing the decision to adopt food safety technologies such as an E. coli vaccine. The current management controls in use by producers are also relevant as these might reflect their perception regarding the ability to control the E. coli pathogen.

The Binary Probit analysis with regard to the individual B-W scores for the 13 incentives were all found to be significant. For those producers that were willing to adopt, the positive signs met *a priori* expectations seeing that incentives are created for the express purpose of stimulating a positive response or outcome. On the other hand, the analysis using the Ordered Probit model showed that for those producers that were unsure about their adoption decision or those that were unwilling to adopt, the incentives all had negative signs. This result might suggest that more would need to be done beyond incentives to encourage adoption of the E. coli vaccine from this sub-set of cow-calf producers. The marginal effects for the 13 incentives were all of a similar magnitude in the Binary Probit model.

Broader implications of this research pertain to the idea of how food safety technologies and other technologies that may improve the overall efficiency of the beef industry are implemented in terms of the evenhandedness of adoption. The notion of how this cost of adoption can be equitably spread throughout the supply chain is explored in the areas of further research. In addition, the BWS results have shed light on the importance and role of downstream market pressure in technology adoption within the beef industry. In particular, the significance of the incentive "my buyer requiring use of vaccine as part of the production protocol as a condition for accepting my calves/cattle" highlights the necessity of downstream market pressure as a valuable component in the adoption of industry defining technologies such as the E. coli vaccine.

As discussed in Chapter 1, policy makers and industry strategists have not prioritized their efforts towards preventative pre-harvest interventions such as the E. coli vaccine due to the previous lack of existence of these technologies, or limited commercial availability. Therefore, facilitating avenues for the wider adoption of food safety technologies such as the E.coli vaccine has implications for the traditional emphasis placed on end products in the value chain, with an impending emergence of an equivalent focus placed on the prevention of food contamination at the source.

Other implications of this research include adoption of a more wholistic approach to food safety, one that encompasses the entire food chain, all the while adhering to the Food and Agriculture Organization's (FAO) definition of a food chain approach, where responsibility for the production of safe food is shared along the entire food/supply chain. This from the perspective that responsibility for adoption in most cases, falls on one set of participants within the supply chain thus not only suggesting absorption of the full cost of adoption, but also creating vulnerabilities of exposure to the pathogen at other points in the supply chain. This vulnerability in turn might lead to the realization of dynamic externalities as outlined in the Anti-Commons section of Chapter 3, where recurring incidences of E. coli take place as a result of the current under-use of production assets. This causes supply and demand disruptions such as the XL Foods Inc. case.

6.3. Limitations of the Research

As in many other studies, practical limitations of this project confined its range. The online producer survey was confined to cow-calf producers located in western Canada who belong to the animal health database of a market research company. An online-based survey was determined to be the more effective means of data collection as it was challenging locating contact details for cow-calf producers. Other alternatives to the online survey were considered, specifically, surveying producers at producer association conferences. This method however, would have also generated its own set of sample biases. Although the online survey sample was broadly representative of Canadian cow-calf producer distribution by province, the selection was not random and as such care needs to be given when extrapolating the results to the broader population of cow-calf producers.

Additional limitations relating to the use of an internet based survey is the possibility that certain populations of cow-calf producers are less likely to have internet access and therefore respond to online questionnaires. However, this limited sampling bias is becoming less of a concern as internet use becomes more ubiquitous among the Canadian population. Furthermore, the possibility of social desirability or agreement bias concerning some of the survey questions related to good management practices, such as the current use of environmental farm plans, may not reflect the state of these practices within the industry at large.

Another limitation pertains to the Best Worst Scaling method. Although the method allows for maximum discrimination and trade-off opportunities as a product of the repeated choice set selection, it contains a threshold that if exceeded can place an enormous cognitive burden on the respondent. The literature suggests that beyond 15 choice sets, respondent fatigue is likely which could lead to response bias. As such, the experimental design for this study was restricted to 13 attributes/incentives which yielded 13 choice sets. Furthermore, the number of incentives selected must match a corresponding statistical/experimental design such as a balanced incomplete block design, as not all numbers are compatible with this design. Thus the choice of the number of incentives and structure of the survey was somewhat driven by the needs of the experimental design. The survey was pre-tested and no major problems were found, nevertheless, it is possible that respondent fatigue may have been an issue.

6.4. Areas for Further Research

Producers were asked who they think should bear the primary responsibility of reducing the risk of E. coli within the supply chain. Most producers indicated that this responsibility belonged to processors/packers. Indeed, the literature on E coli contamination shows that there are many points in the supply chain at which the risks of E. coli contamination can be mitigated, only one of which is on the farm. Feedlots, retailers, consumers, and in particular, processors/packers are other important points in the supply chain with a role to play in reducing food safety hazards. An important area of future research therefore is to explore the specific role of processors/packers in reducing E. coli risks and the factors affecting the willingness of packers to adopt food safety technologies and food safety mitigation strategies. This might include the willingness of packers to engage in source and pay premiums for E. coli vaccinated cattle, provided that processors/packers are willing to put the market/supply chain incentives in place as these were found to be the most important.

As noted in the previous chapters, upstream participants allocate their resources in response to the market pressures and incentives from downstream supply chain participants. With this in mind, if processors/packers were to require evidence of E. coli vaccines as part of upstream production protocol, adoption rates among cow-calf producers would likely increase. How would this widespread adoption affect the role of processors/packers in the control of the E. coli pathogen? If upstream participants use the vaccine as a measure to combat E. coli outbreaks, how would this affect the current preventative efforts that are in use at the processor/packer stage of production such as HACCP? The concept of moral hazard might come into play in this case; as E. coli controls upstream become more effective, would downstream participants such as processors/packers ease the food safety risk reduction measures they have in place? Many interesting questions therefore arise with respect to how adoption of the E coli vaccine by cow-calf producers would affect the behavior of other supply chain participants and are fruitful areas for further research.

Based on the results from this thesis, the possibility of closer supply chain co-ordination increasing the current low adoption is real. Such a mechanism can be put in place through use of governance structures such as branded beef alliances, which may be a vehicle for the more influential market/supply chain incentives noted earlier. Another area of future research therefore is to examine other ways in which wider adoption can be achieved. Food safety technologies such as the E. coli vaccine as noted in the literature often suffer from the expectation that one element within the supply chain will bear the full cost of adoption, in this case cow-calf producers.

Bearing in mind that the original research into the E. coli vaccine was funded by the Canadian Cattlemen's Association, a producer association, it would be interesting to explore the role of producer associations, both nationally and provincially, in influencing the development and adoption of food safety technologies through use of national check-off funding. The goal of national check-offs is to find better and more efficient ways of producing high quality cattle and beef through research, to increase sales in the domestic and export markets. Research into a whole supply chain approach to mitigating E. coli risk (i.e. including but not limited to E. coli vaccinations by cow-calf producers) can therefore be useful in encouraging an evenhanded approach. This may reduce the potential of supply chain and demand disruptions as a result of E. coli outbreaks, while simultaneously expanding opportunities of finding new sets of buyers willing to pay premiums for the use of food safety technologies.

6.5. Conclusions

This thesis has outlined a set of most and least influential incentives that can be considered in addressing the current low adoption rates of the E. coli vaccine as mitigation for the risk of E. coli incidences. Results indicate that cow-calf producers respond to market/supply chain incentives; however, these incentives are currently not in place to address the low adoption of the E. coli vaccine. Furthermore, possible barriers were examined together with several drivers that can affect a cow-calf producer's propensity to adopt the vaccine technology. The results indicate that for the majority of cow-calf producers, once the right incentives are in place, their willingness to adopt a socially beneficial technology such as an E. coli vaccine increases. The existence of unique segments of cow-calf producers can aid in the creation of industry strategies that can assist in the adoption of socially beneficial technologies such as the E. coli vaccine through a more targeted approach.

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8. APPENDICES

Appendix 1: Canadian Cow-Calf Producer Survey

You are invited to participate in a study entitled: ***Incentives to adopt an E. coli cattle vaccine***

Principal Investigator: Jill E. Hobbs, Ph.D. Professor, Department of Bioresource Policy, Business and Economics, University of Saskatchewan, Saskatoon, SK
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Purpose and procedure: We would like your responses to some questions about your awareness of E. coli, risk management practices in use in the beef industry, and your assessment of the factors affecting adoption of an E. coli vaccine for cattle. The data collected through this survey will be used in a Master's thesis in the Department of Bioresource Policy, Business and Economics at the University of Saskatchewan.

This research project is coordinated by the Department of Bioresource Policy, Business and Economics at the University of Saskatchewan. The results of this research will be used for a master's thesis in Agricultural Economics.

Your participation in this study is appreciated and voluntary. It is expected that the survey should take about 20 minutes to complete.

Potential Benefits: Your participation in this study will help improve our understanding of the incentives and barriers to the adoption of an E. coli vaccine. The research has the potential to inform food safety management and supply chain strategies in the Canadian beef sector

Potential Risks: No known or foreseeable human risk will be involved in completing the survey.

Storage of Data: The data from the survey will be securely stored in the Department of Bioresource Policy, Business & Economics at the University of Saskatchewan. The data will be destroyed, after at least 5 years, when it is no longer required.

Confidentiality: Data will be combined and aggregated to protect individual respondents. The research conclusions will be published in a variety of formats, both print and electronic. These materials will be used in the development of a Master's Thesis and may be further used for purposes of conference presentations, or publication in academic journals, books or popular press. In these publications, the data will be reported in a manner that protects confidentiality and the anonymity of participants.

Right to Withdraw: Participation in this survey is voluntary, and you can decide not to participate at any time by closing your browser Survey responses will remain anonymous. Since the survey is anonymous, once you have submitted the survey your responses can no longer be removed.

Questions: If you have any questions concerning the research project, please feel free to contact the researchers at the phone numbers or email addresses provided above.

This research project has been approved on ethical grounds by the University of Saskatchewan Research Ethics Board on June 27th 2014. Any questions regarding your rights as a participant may be addressed to that committee through the Research Ethics Office ethics.office@usask.ca (306) 966-2975. Out of town participants may call toll free (888) 966-2975.

Consent to Participate: *I have read and understood the description provided above. Completion of this survey will constitute consent to participate and permission for the researcher to use the data gathered in the manner described. If you would like a copy of this consent form for your record, please contact the Principal Investigator: Dr. Jill Hobbs, Phone: 306-966-2445 or Email: jill.hobbs@usask.ca.*

- ☐ ***I Accept***
- ☐ ***I Decline***

Thank you. We would like you to participate in our study.

Qualifiers

A. How many beef cows do you currently have in your operation?

[IF > 0 CONTINUE]

B. To confirm, are you the person that has overall or joint responsibility for the animal health management practices you use for your cow-calf operation?

Yes
No

[IF YES, CONTINUE]

[SURVEY]

1. What is your primary role on the farm? *(Please select one response)*
   - Owner
   - Co-owner
   - Manager
   - Employee
2. Do you retain ownership of your cattle/calves during the feeding/finishing process?
   - Yes
   - No
3. How do you market the majority of your cattle/calves? *(Please select one response)*
   - Contracts with feedlots
   - Auction barns
   - Forward pricing
   - Breed influenced programs
   - Age-and-source verification programs
   - Direct marketing to consumers/restaurants
   - Natural or certified organic marketing
4. Have you ever participated as a supplier in a branded beef program(s)? (E.g. Certified Angus Beef; SYSCO Butcher's Block Reserve; Sterling Silver Premium Beef or similar programs).
   - Yes
   - No

[IF YES, CONTINUE – OTHERWISE SKIP TO Q.6]

5. What is/are the names of the branded beef programs you have participated in?

6. How familiar would you say you are with E. coli?

- Very Unfamiliar
- Somewhat Unfamiliar
- Somewhat Familiar
- Very Familiar

7. How familiar would you say you are with E. coli outbreaks that have taken place in Canada since the year 2000?
    - Very Unfamiliar
    - Somewhat Unfamiliar
    - Somewhat Familiar
    - Very Familiar

[IF SOMEWHAT FAMILIAR OR VERY FAMILIAR IN Q.7, CONTINUE – OTHERWISE SKIP TO Q.9]

8. Please list one/some of the E.coli outbreaks you're familiar with that have taken place in Canada since the year 2000.

9. Which, if any, of the following ways have recent E. coli outbreaks in Canada reduced the value of - or created problems for your cow-calf operation? *(Please select all that apply)*
    - Increased extra days to feed due to blocked market access
    - Buyers not accepting my cattle
    - Increased costs due to extra bio-security measures put in place
    - Resulted in training of employees on new management practices
    - My cow-calf operation has been improved by recent E. coli outbreaks (E.g. encouraged me to be more proactive with my environmental or animal health practices)
    - My cow-calf operation has not been affected at all

10. Who/where is your primary source of information regarding E. coli? *(Please check all that apply)*
    - Producer associations (e.g. provincial or national cattle industry associations)

- My veterinarian
- Consultants
- Government information services (e.g. provincial ministries of Agriculture)
- Internet searches
- Other cow-calf producers
- Pharmaceutical companies
- I have no source of information regarding E.coli [EXCLUSIVE RESPONSE]

[IF "I HAVE NO SOURCE OF INFORMATION REGARDING E.COLI" SELECTED IN Q.10 – SKIP TO Q.12]

11. Which of the following sources do you consult first regarding E.coli?
    - Producer associations (e.g. provincial or national cattle industry associations)
    - My veterinarian
    - Consultants
    - Government information services (e.g. provincial ministries of Agriculture)
    - Internet searches
    - Other cow-calf producers
    - Pharmaceutical companies

12. Do you currently vaccinate your calves against any form of disease?
    - Yes
    - No

    [IF YES, CONTINUE – OTHERWISE SKIP TO Q.16]

13. About how often are most of your calves vaccinated?
    - Once a year
    - Twice a year
    - More than twice

14. Who typically vaccinates your calves? *(Please select all that apply)*
    - Local veterinarian

- I do it myself
- I do it myself with supervision from the veterinarian
- An employee does it

15. About how much do you spend in total on vaccines per year per calf?

    - Less than $1
    - $1 - $4.99
    - $5 - $6.99
    - More than $7

16. Have you ever heard of an E. coli vaccine, such as the brand Econiche?
    - Yes, I have used an E.coli vaccine and am currently still using it
    - Yes, I have used an E.coli vaccine
    - Yes, I have heard of an E.coli vaccine but have not used one
    - No, I have never heard of an E.coli vaccine

    [IF NO IN Q.16 SKIP TO Q.20]

16.a Approximately what percentage of your beef cattle are vaccinated with an E.coli vaccine?

[IF YES, I HAVE HEARD OF AN E.COLI VACCINE BUT HAVE NOT USED ONE IN Q.16 – SKIP TO Q.18]

17. Which of the following reasons indicate why you use/have used an E. coli vaccine ***(please check all that apply)***
    - My veterinarian suggested use of the vaccine
    - I used it on a trial basis
    - I wanted a way to differentiate my cattle in the marketplace
    - I found a buyer willing to pay a premium
    - Other reason (Please type in)
18. Are you aware of the cost of the E. coli vaccine?
    - Yes
    - No

19. Are you confident in the level of immunization the E. coli vaccine provides?
    - Yes
    - No
20. In your opinion, who has the <u>primary</u> responsibility for reducing the risk of E. coli problems within the beef supply chain? *(Please check one response)*
    - Cow-calf producers
    - Feedlots
    - Processors/ Packers
    - Retailers
    - Consumers
    - Regulators (e.g. Canadian Food Inspection Agency)
21. In your opinion, who has the <u>secondary</u> responsibility? *(Please check one response)*
    - Cow-calf producers
    - Feedlots
    - Processors/Packers
    - Retailers
    - Consumers
    - Regulators (e.g. Canadian Food Inspection Agency)
22. In your opinion who would benefit the most from a cattle vaccine to reduce colonization and shedding of E. coli by cattle? *(Please check one response)*
    - Cow-calf producers
    - Feedlots
    - Processors/Packers
    - Retailers
    - Consumers
    - Municipal water security agencies
23. What proportion of the cost of an E. coli vaccination program should be borne by the following groups? <u>**Please allocate 100 percentage points across the following groups. The more you feel a particular group should bear the cost of an E.coli vaccination**</u>

<u>program, the more percentage points should be given to it. You may give all or none of the 100 percentage points to a group, but your total must equal 100.</u>

- Cow-calf producers
- Feedlots
- Processor/Packers
- Retailers
- Consumers
- Municipal water security agencies

24. Which of the following interventions/management practices to mitigate E. coli incidences in your cow-calf operation do you currently use, if any?

INTERVENTIONS/MANAGEMENT CONTROLS	
Removing of farm animals from the proximity of private water supplies (e.g. At least 50m from well, borehole or other private water supply by fencing-off)	○ Yes ○ No ○ Not applicable
Prohibit recreational activities (such as walking and camping) on land where manure or slurry have been applied, or animals and faeces present, in previous 4 weeks.	○ Yes ○ No ○ Not applicable
Monitoring of private water supplies to identify those with either high indicator or counts, or those in areas of high risk.	○ Yes ○ No ○ Not applicable
Treatment of water supplies by ozonation, chlorination or ultra-violet treatment.	○ **Yes** ○ **No** ○ **Not applicable**
Stop run-off from adjacent manured fields using vegetative buffer strips to control contamination of ready-to-eat crops.	○ Yes ○ No ○ Not applicable
Keep livestock and/or pets out of ready-to-eat crop areas, using fencing.	○ Yes ○ No ○ Not applicable

Fence-off streams from livestock.	○ Yes ○ No ○ Not applicable
Vaccinate cattle to control pathogen colonization and faecal excretion of E. coli.	○ Yes ○ No ○ Not applicable
Use probiotics to reduce E. coli shedding rates (e.g. E. Coli and lactobacillus strains).	○ Yes ○ No ○ Not applicable
Prevent contact with neighbouring cows via double fencing.	○ Yes ○ No ○ Not applicable
Not mixing groups of young stock once formed so as to prevent direct and indirect transmission of pathogens.	○ Yes ○ No ○ Not applicable
Prevention of ground water contamination from farm run-off.	○ Yes ○ No ○ Not applicable
Use of an environmental farm plan.	○ Yes ○ No ○ Not applicable
Other (*Please type in)*	

[IF "YES, I HAVE USED AN E.COLI VACCINE AND AM CURRENTLY STILL USING IT" SELECTED IN Q.16 – SKIP TO Q.26]

25. We are interested in whether you would be more likely to use an E. coli vaccine if other cow calf producers were using the vaccine. Please indicate on a scale of 0 to 100% what proportion of cow-calf producers would need to use an E.coli vaccine before you would consider using an E.coli vaccine. Or, if it would not make a difference to you what percentage of cow-calf producers would need to use an E.coli vaccine before you would consider using an E.coli vaccine, please select "It would not make a difference".

    _____%

    Or,

- ○ It would not make a difference

Best-Worst Choice Tasks

26. Please Read Carefully

Imagine that you are considering using an E. coli vaccine. Calves/cattle are asymptomatic carriers of the E. coli pathogen, meaning that the pathogen does not affect the health of the animal but could increase the risk of E. coli problems in the food supply chain or the environment. We are interested in learning to what extent the following incentives would influence your decision to use an E. coli vaccine.

In what follows you will see a series of 13 choice sets. For each of the following choice sets, tick (click) the ONE incentive that will MOST influence your decision whether to adopt the vaccine and the ONE that will LEAST influence this decision.

Most Desirable (tick one)	**Of these incentives, which would be Most likely to influence and Least likely to influence your adoption of an E.coli vaccine...**	**Least Desirable (tick one)**
○	Beef products from my calves/cattle can be traced back to my farm	○
○	Premiums for E. coli vaccinated cattle are available through various programs (e.g. branded beef program) within the supply chain.	○
○	Recommendation from my veterinarian to use the E. coli vaccine in my operations	○
○	Subsidy to compensate the costs of my adoption of the vaccine is available through a government funded vaccination program.	○

For the 2nd choice set, please tick (click) the ONE incentive that will MOST influence your decision whether to adopt the vaccine and the ONE that will LEAST influence this decision.

Most Desirable (tick one)	**Of these incentives, which would be Most likely to influence and Least likely to influence your adoption of an E.coli vaccine**	**Least Desirable (tick one)**
○	Premiums for E. coli vaccinated cattle are available through various programs (e.g. branded beef program) within the supply chain.	○
○	Government recommending use of E. coli vaccine for cattle	○
○	My reputation as a cattle producer is at risk because of higher consumer expectations concerning food safety	○
○	My buyer requiring use of an E. coli vaccine as part of production protocol as a condition for accepting my calves/cattle	○

For the 3rd choice set, please tick (click) the ONE incentive that will MOST influence your decision whether to adopt the vaccine and the ONE that will LEAST influence this decision.

Most Desirable (tick one)	**Of these incentives, which would be Most likely to influence and Least likely to influence your adoption of an E.coli vaccine**	**Least Desirable (tick one)**
○	Government recommending use of E. coli vaccine for cattle	○
○	Recommendation from my veterinarian to use the E. coli vaccine in my operation.	○
○	Feedlots providing an assurance that they will give my cattle a booster of the E. coli vaccine to maintain the immunity of my cattle.	○
○	Duration of immunity for my calves/cattle is greater than 6 months.	○

For the 4th choice set, please tick (click) the ONE incentive that will MOST influence your decision whether to adopt the vaccine and the ONE that will LEAST influence this decision.

Most Desirable (tick one)	**Of these incentives, which would be Most likely to influence and Least likely to influence your adoption of an E.coli vaccine**	**Least Desirable (tick one)**
○	Recommendation from my veterinarian to use the E. coli vaccine in my operations	○
○	My reputation as a cattle producer is at risk because of higher consumer expectations concerning food safety.	○
○	I can include an E. coli vaccination in my existing vaccination routine.	○
○	Through vaccination, my farm is less exposed to the effects of E. coli outbreaks such as beef recalls and supply disruptions at packing plants.	○

For the 5th choice set, please tick (click) the ONE incentive that will MOST influence your decision whether to adopt the vaccine and the ONE that will LEAST influence this decision.

Most Desirable (tick one)	**Of these incentives, which would be Most likely to influence and Least likely to influence your adoption of an E.coli vaccine**	**Least Desirable (tick one)**
○	My reputation as a cattle producer is at risk because of higher consumer expectations concerning food safety.	○
○	Feedlots providing an assurance that they will give my cattle a booster of the E. coli vaccine to maintain the immunity of my cattle.	○
○	Attraction of a new set of buyers for my vaccinated cattle	○
○	Beef products from my calves/cattle can be traced back to my farm	○

For the 6th choice set, please tick (click) the ONE incentive that will MOST influence your decision whether to adopt the vaccine and the ONE that will LEAST influence this decision.

Most Desirable (tick one)	**Of these incentives, which would be Most likely to influence and Least likely to influence your adoption of an E.coli vaccine**	**Least Desirable (tick one)**
○	Feedlots providing an assurance that they will give my cattle a booster of the E. coli vaccine to maintain the immunity of my cattle.	○
○	I can include an E. coli vaccination in my existing vaccination routine.	○
○	My neighbours (other cattle producers) are adopting the E. coli vaccine	○
○	Premiums for E. coli vaccinated cattle are available through various programs (e.g. branded beef program) within the supply chain.	○

For the 7th choice set, please tick (click) the ONE incentive that will MOST influence your decision whether to adopt the vaccine and the ONE that will LEAST influence this decision.

Most Desirable (tick one)	**Of these incentives, which would be Most likely to influence and Least likely to influence your adoption of an E.coli vaccine**	**Least Desirable (tick one)**
○	I can include an E. coli vaccination in my existing vaccination routine.	○
○	Attraction of a new set of buyers for my vaccinated cattle	○
○	Subsidy to compensate the costs of my adoption of the vaccine is available through a government funded vaccination program.	○
○	Government recommending use of E. coli vaccine for cattle	○

For the 8th choice set, please tick (click) the ONE incentive that will MOST influence your decision whether to adopt the vaccine and the ONE that will LEAST influence this decision.

Most Desirable (tick one)	Of these incentives, which would be Most likely to influence and Least likely to influence your adoption of an E.coli vaccine	Least Desirable (tick one)
○	Attraction of a new set of buyers for my vaccinated cattle.	○
○	My neighbours (other cattle producers) are adopting the E. coli vaccine.	○
○	My buyer requiring use of vaccine as part of production protocol as a condition for accepting my calves/cattle.	○
○	Recommendation from my veterinarian to use the E. coli vaccine in my operations.	○

For the 9th choice set, please tick (click) the ONE incentive that will MOST influence your decision whether to adopt the vaccine and the ONE that will LEAST influence this decision.

Most Desirable (tick one)	Of these incentives, which would be Most likely to influence and Least likely to influence your adoption of an E.coli vaccine	Least Desirable (tick one)
○	My neighbours (other cattle producers) are adopting the E. coli vaccine	○
○	Subsidy to compensate the costs of my adoption of the vaccine is available through a government funded vaccination program.	○
○	Duration of immunity for my calves/cattle is greater than 6 months.	○
○	My reputation as a cattle producer is at risk because of higher consumer expectations concerning food safety.	○

For the 10th choice set, please tick (click) the ONE incentive that will MOST influence your decision whether to adopt the vaccine and the ONE that will LEAST influence this decision.

Most Desirable (tick one)	**Of these incentives, which would be Most likely to influence and Least likely to influence your adoption of an E.coli vaccine**	**Least Desirable (tick one)**
○	Subsidy to compensate the costs of my adoption of the vaccine is available through a government funded vaccination program.	○
○	My buyer requiring use of E. coli vaccine as part of production protocol as a condition for accepting my calves/cattle.	○
○	Through vaccination, my farm is less exposed to the effects of E. coli outbreaks such as beef recalls and supply disruptions at packing plants.	○
○	Feedlots providing an assurance that they will give my cattle a booster of the E. coli vaccine to maintain the immunity of my cattle.	○

For the 11th choice set, please tick (click) the ONE incentive that will MOST influence your decision whether to adopt the vaccine and the ONE that will LEAST influence this decision.

Most Desirable (tick one)	**Of these incentives, which would be Most likely to influence and Least likely to influence your adoption of an E.coli vaccine**	**Least Desirable (tick one)**
○	My buyer requiring use of E. coli vaccine as part of production protocol as a condition for accepting my calves/cattle.	○
○	Duration of immunity for my calves/cattle is greater than 6 months.	○
○	Beef products from my calves/cattle can be traced back to my farm	○
○	I can include an E. coli vaccination in my existing vaccination routine.	○

For the 12th choice set, please tick (click) the ONE incentive that will MOST influence your decision whether to adopt the vaccine and the ONE that will LEAST influence this decision.

Most Desirable (tick one)	**Of these incentives, which would be Most likely to influence and Least likely to influence your adoption of an E.coli vaccine**	**Least Desirable (tick one)**
○	Duration of immunity for my calves/cattle is greater than 6 months.	○
○	Through vaccination, my farm is less exposed to the effects of E. coli outbreaks such as beef recalls and supply disruptions at packing plants	○
○	Premiums for E. coli vaccinated cattle are available through various programs (e.g. branded beef) within the supply chain.	○
○	Attraction of a new set of buyers for my vaccinated cattle.	○

For the 13th and last choice set, please tick (click) the ONE incentive that will MOST influence your decision whether to adopt the vaccine and the ONE that will LEAST influence this decision.

Most Desirable (tick one)	**Of these incentives, which would be Most likely to influence and Least likely to influence your adoption of an E.coli vaccine**	**Least Desirable (tick one)**
○	Through vaccination, my farm is less exposed to the effects of E. coli outbreaks such as beef recalls and supply disruptions at packing plants	○
○	Beef products from my calves/cattle can be traced back to my farm	○
○	Government recommending use of E. coli vaccine for cattle	○
○	My neighbours (other cattle producers) are adopting the E. coli vaccine.	○

27. Would you consider adopting an E. coli vaccine if presented with the right incentives such as some of those appearing above?
    - ○ Yes
    - ○ No
    - ○ Don’t know/Unsure

28. Please indicate whether the following issues deter you from adopting an E. coli vaccine.

Lots of changes to my vaccination protocols would be needed before E. coli vaccines can be made part of my production process.	○ Yes ○ No
Challenges associated with adoption of an E.coli vaccine are not easily overcome such as not enough of my neighbours (other cattle producers) adopting the vaccine to mitigate E. coli	○ Yes ○ No
Greater priority is given to other issues other than enhancing my food safety controls in my cattle operation.	○ Yes ○ No
I am uncertain whether the adoption of the E. coli vaccine would meet the need of the buyer(s) of my cattle	○ Yes ○ No
Food safety issues are not sufficiently important to warrant the investment in the E. coli vaccine	○ Yes ○ No
I am uncertain about whether adoption of the E. coli vaccine will improve food safety	○ Yes ○ No
E. coli vaccine goes against all of the ways in which my farm has traditionally done things	○ Yes ○ No
The additional cost is not warranted	○ Yes ○ No
There is too much uncertainty about the pay-off/premiums as a result of adoption of an E.coli vaccine	○ Yes ○ No

29. Please indicate your agreement with the following statements using the scale where (1 = completely disagree, 2 = somewhat disagree, 3 = Neutral, 4 = somewhat agree, 5 = completely agree) by clicking on appropriate response.

Completely Disagree 1	Somewhat Disagree 2	Neutral 3	Somewhat Agree 4	Completely Agree 5

a. I feel in control of potential E. coli contamination due to my existing management practices/interventions.

b. Whether or not I'm successful in mitigating/controlling E. coli depends mostly on my own ability.

c. To a great extent E. coli incidences on my cow-calf operation are determined by factors beyond my control

d. To a great extent E. coli incidences on my cow-calf operation are determined by the management practices I have in place.

e. My success as a cow-calf operator depends mostly on luck.

f. It is not advisable for me to plan too far ahead by enhancing my current management practices because E. coli incidences are such that they cannot be fully prevented.

The following questions are designed to tell us a little about you and your cow-calf operation. This information will be aggregated and used to report comparisons among groups of respondents. Your identity will not be linked to your responses in any way.

30. Gender:

- o Male
- o Female

31. In what year you were born?

Decline to respond

32. In which province or territory is your cow-calf operation located?

- o BC
- o AB
- o SK
- o MB

33. Please provide the first three letters of your postal code…

34. What best describes your highest level of education? *(Please select one that applies)*

- o Primary/Elementary
- o Secondary/High School
- o Trade School/College
- o University

35. How many years have you been a principal decision maker in your cow-calf operation?

- o Less than 4 years
- o 5-20 years
- o 21-35 years
- o 35 years and over

36. How long do you plan on continuing being a cow-calf producer?

- o Less than 1 year
- o 1 – 5 years
- o 6 – 10 years
- o 10 – 25 years
- o More than 25 years

37. What percentage of your total 2013 gross farm sales/revenues is derived from your cow-calf operations?

38. How important is your cow-calf operation to your livelihood?

- Not at all important
- Fairly important
- Very important
- Essential

39. That completes our survey. Do you have any further comments?

Thank you very much for your time and participation in our survey. Your input is greatly appreciated.

Appendix 2: Ordered Probit Models

Following Verbeek (2004), the equations (A2.16) below show the probabilities of the 3 available choices being selected.

$$\text{Prob}\ (y = 0 \mid x) = P\ (y^* \leq \alpha_1 \mid x)$$

$$= P\ (x\beta + \varepsilon \leq \alpha_1 \mid x)$$

$$= P\ (\varepsilon \leq \alpha_1 - x\beta \mid x)$$

$$= \Phi\ (\alpha_1 - x\beta)$$

$$\text{Prob}\ (y = 1 \mid x) = P\ (\alpha_1 < y^* \leq \alpha_2 \mid x)$$

$$= P\ (\alpha_1 < x\beta + \varepsilon \leq \alpha_2 - x\beta)$$

$$= P\ (\alpha_1 - x\beta < \varepsilon \leq \alpha_2 - x\beta)$$

$$= \Phi\ (\alpha_1 - x\beta) - \Phi\ (\alpha_2 - x\beta)$$

$$\text{Prob}\ (y = 3 \mid x) = P\ (\alpha_2 > y^* \mid x)$$

$$= P\ (\alpha_2 > x\beta + \varepsilon \mid x)$$

$$= 1 - \Phi\ (\alpha_2 - x\beta) \qquad \text{(A2.16)}$$

As noted earlier, the alphas represent cut-off points or thresholds levels. The assumption is that an individual is willing to adopt an E. coli vaccine if the utility difference exceeds a certain threshold level. Consequently we observe $y_i = 2$ (willingness to adopt: yes) if and only if $y_i^* > 0$ and $y_i = 0$ (No) otherwise.

Thus substituting the appropriate form for Φ (.) gives an expression that can be maximized with respect to β using the method of maximum likelihood.

The likelihood function becomes:

$$(14)\ \text{Ln } L = \sum I_{yi=0} \ln\Phi\ (\alpha_1 - x\beta) + I_{yi=1} \ln\ [\Phi\ (\alpha_1 - x\beta) - \Phi\ (\alpha_2 - x\beta)] + I_{yi=2} \ln\ [1- (\Phi\ (\alpha_2 - x\beta)] \qquad \text{(A2.17)}$$

Where I_k is an indicator function for willingness to adopt; Φ (.) is defined to be the cumulative distribution and ln being the natural logs.

A2.1: Ordered Probit Model with all estimated variables included

Variable	**Coefficient**	**Std. Err.**	**P value**
Gender	0.388	0.280	0.166
Age	0.011	0.017	0.523
Level of education	0.388*	0.219	0.076
Awareness of technology	0.660***	0.221	0.003
Primary Responsibility of E. coli reduction – Feedlots	-0.748*	0.419	0.074
Primary Responsibility of E. coli reduction – Processor/Packer	-0.272	0.351	0.439
Primary Responsibility of E. coli reduction – Consumers	-1.084**	0.485	0.026
Primary Responsibility of E. coli reduction – Regulators	-1.175**	0.546	0.031
Retain ownership of cattle	-0.052	0.222	0.815
Size of operation	0.000	0.000	0.809
Importance of operations to Livelihood	0.443	0.275	0.107
Experience as principal decision maker	-0.014	0.016	0.377
Alberta	-0.239	0.254	0.347
Manitoba	-0.143	0.310	0.644
Benefits	0.177	0.289	0.541
Continuity as a cow-calf producer	0.004	0.018	0.841
Sales/Revenue derived from operations	0.001	0.004	0.837
Internal Locus of control	-0.019	0.143	0.893
External Locus of control	-0.369**	0.156	0.018
Beef products can be traced to my farm	0.840***	0.259	0.001
Premiums available through branded programs	0.745***	0.249	0.003
Recommendation from my veterinarian	0.707***	0.247	0.004
Subsidy to compensate cost of adoption available	0.681***	0.241	0.005
Government recommending use of vaccine	0.651**	0.245	0.008
My reputation as producer is at risk	0.724***	0.238	0.002
My buyer requiring use of vaccine	0.748***	0.251	0.003
Feedlots providing assurance for a booster	0.761***	0.251	0.002
Duration of immunity greater than 6 months	0.717***	0.249	0.004

Through Vaccination I can reduce supply disruptions	0.798***	0.255	0.002
My neighbours adopting vaccine	0.689***	0.243	0.005
Attraction of a new set of buyers	0.556***	0.235	0.005
I can include vaccine in an existing vaccination routine	0.671**	0.253	0.008
N	203		
Pseudo R-sq.	0.194		

* p<0.1, ** p<0.05, *** p<0.01

The performance of the Ordered Probit model in relation to the Binary Probit model was relatively comparable as noted earlier. However, changes in the level of significance highlighted the major differences with level of education and perception of responsibility, particularly pertaining to processors/packers. A noticeable change was the weak significance of the importance of operations to a producer's livelihood.

A2.2: Ordered Probit Model with Significant Variables

Variable	**Coefficient**	**Std. Err.**	**P value**
Level of education	0.380*	0.207	0.067
Awareness of technology	0.664***	0.212	0.002
Primary Responsibility of E. coli reduction - Feedlots	-0.638	0.404	0.114
Primary Responsibility of E. coli reduction – Processor/Packer	-0.292	0.339	0.388
Primary Responsibility of E. coli reduction – Consumers	-0.948**	0.462	0.040
Primary Responsibility of E. coli reduction - Regulators	-1.083**	0.527	0.040
External Locus of control	-0.385***	0.140	0.006
Beef products can be traced to my farm	0.694****	0.240	0.004
Premiums available through branded programs	0.611****	0.231	0.008
Recommendation from my veterinarian	0.589**	0.230	0.010
Subsidy to compensate cost of adoption available	0.544**	0.222	0.014
Government recommending use of vaccine	0.542**	0.229	0.018
My reputation as producer is at risk	0.621***	0.224	0.006
My buyer requiring use of vaccine	0.600**	0.232	0.010
Feedlots providing assurance for a booster	0.663***	0.236	0.005
Duration of immunity greater than 6 months	0.620***	0.233	0.008
Through Vaccination I can reduce supply disruptions	0.700***	0.238	0.003
My neighbours adopting vaccine	0.564**	0.225	0.012
Attraction of a new set of buyers	0.462**	0.220	0.036
I can include vaccine in an existing vaccination routine	0.566**	0.238	0.017
N	203		
Pseudo R-sq.	0.169		

* p<0.1, ** p<0.05, *** p<0.01

A2.3: Ordered Probit Model Marginal Effects for Producers' Willingness to Adopt

Marginal effects after OProbit
y = Pr (wtao == 3) (predict, outcome (3))
= .75469531

Variable	Dy/Dx	Std. Err.	P value
Level of education	0.123	0.068	0.071
Awareness of technology	0.214	0.068	0.002
Primary Responsibility of E. coli reduction - Feedlots	-0.225	0.152	0.137
Primary Responsibility of E. coli reduction – Processor/Packer	-0.091	0.103	0.378
Primary Responsibility of E. coli reduction – Consumers	-0.351	0.177	0.047
Primary Responsibility of E. coli reduction - Regulators	-0.404	0.195	0.039
External Locus of control	-0.121	0.044	0.006
Beef products can be traced to my farm	0.218	0.074	0.003
Premiums available through branded programs	0.192	0.072	0.007
Recommendation from my veterinarian	0.185	0.071	0.009
Subsidy to compensate cost of adoption available	0.171	0.069	0.013
Government recommending use of vaccine	0.170	0.071	0.017
My reputation as producer is at risk	0.195	0.069	0.005
My buyer requiring use of vaccine	0.188	0.072	0.009
Feedlots providing assurance for a booster	0.208	0.073	0.004
Duration of immunity greater than 6 months	0.195	0.072	0.007
Through Vaccination I can reduce supply disruptions	0.220	0.074	0.003
My neighbours adopting vaccine	0.177	0.070	0.011
Attraction of a new set of buyers	0.145	0.068	0.034
I can include vaccine in an existing vaccination routine	0.178	0.074	0.016

Table A2.4 and A2.5 show that the marginal effects of all the incentives bear negative signs, indicating an inverse relationship exists between these incentives and the ‘no’ and ‘unsure/don’t know’ producer responses. An increase in the incentives for adoption would still lead to a decrease in these categories. The Ordered Probit model therefore allows for additional information representative of the sub-groups of adopters to be examined as can be seen in the separate marginal effects results.

A2.4: Ordered Probit Model Marginal Effects for adopters that don't know or are unsure about adoption decision

Marginal effects after OProbit

y = Pr (wtao==Don't Know/Unsure) (predict, outcome (2))

= .22813041

Variable	Dy/Dx	Std. Err.	P value
Level of education	-0.105	0.058	0.070
Awareness of technology	-0.181	0.059	0.002
Primary Responsibility of E. coli reduction - Feedlots	0.181	0.112	0.106
Primary Responsibility of E. coli reduction – Processor/Packer	0.078	0.089	0.378
Primary Responsibility of E. coli reduction – Consumers	0.258	0.103	0.013
Primary Responsibility of E. coli reduction - Regulators	0.281	0.095	0.003
External Locus of control	0.105	0.039	0.008
Beef products can be traced to my farm	-0.189	0.067	0.005
Premiums available through branded programs	-0.166	0.064	0.010
Recommendation from my veterinarian	-0.160	0.064	0.012
Subsidy to compensate cost of adoption available	-0.148	0.062	0.017
Government recommending use of vaccine	-0.147	0.064	0.020
My reputation as producer is at risk	-0.169	0.063	0.007
My buyer requiring use of vaccine	-0.163	0.064	0.011
Feedlots providing assurance for a booster	-0.180	0.066	0.006
Duration of immunity greater than 6 months	-0.169	0.065	0.009
Through Vaccination I can reduce supply disruptions	-0.190	0.067	0.004
My neighbours adopting vaccine	-0.153	0.062	0.014
Attraction of a new set of buyers	-0.126	0.060	0.038
I can include vaccine in an existing vaccination routine	-0.154	0.066	0.020

A2.5: Ordered Probit Model for unwilling Adopters

Marginal effects after OProbit

y = Pr (wtao== No) (predict, outcome (1))

= .01717428

Variable	Dy/Dx	Std. Err.	P value
Level of education	-0.018	0.013	0.153
Awareness of technology	-0.033	0.016	0.040
Primary Responsibility of E. coli reduction - Feedlots	0.044	0.043	0.308
Primary Responsibility of E. coli reduction – Processor/Packer	0.012	0.015	0.406
Primary Responsibility of E. coli reduction – Consumers	0.093	0.082	0.256
Primary Responsibility of E. coli reduction - Regulators	0.123	0.112	0.273
External Locus of control	0.016	0.008	0.044
Beef products can be traced to my farm	-0.029	0.014	0.037
Premiums available through branded programs	-0.026	0.013	0.047
Recommendation from my veterinarian	-0.025	0.013	0.051
Subsidy to compensate cost of adoption available	-0.023	0.012	0.057
Government recommending use of vaccine	-0.023	0.012	0.062
My reputation as producer is at risk	-0.026	0.013	0.040
My buyer requiring use of vaccine	-0.025	0.013	0.050
Feedlots providing assurance for a booster	-0.028	0.014	0.040
Duration of immunity greater than 6 months	-0.026	0.013	0.046
Through Vaccination I can reduce supply disruptions	-0.030	0.014	0.036
My neighbours adopting vaccine	-0.024	0.012	0.054
Attraction of a new set of buyers	-0.020	0.011	0.084
I can include vaccine in an existing vaccination routine	-0.024	0.013	0.061

Appendix 3: Distribution of size of operation among survey respondents (herd size)

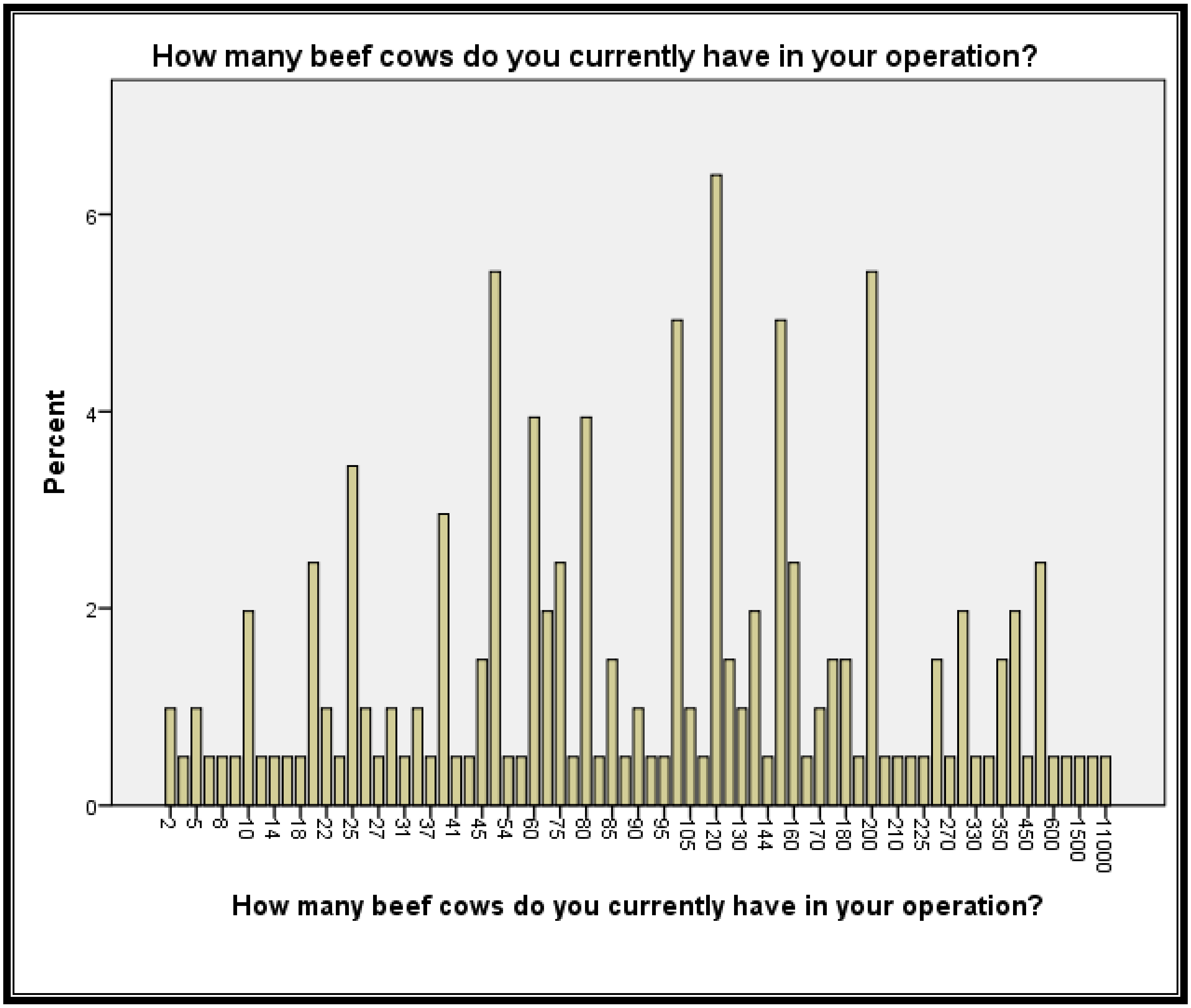

Figure A3. 1: Distribution of size of operation (herd size)